YUKON RIVER BASIN STUDY

This project was completed for the Yukon River Basin Study, an intergovernmental study funded by the governments of Canada, Yukon and British Columbia.

Yukon River Basin Study
Project Report: Energy 5

STORAGE AND THE YUKON HYDROELECTRIC POTENTIAL

A Long Range Planning Issue

Commissioned by Northern Canada Power Commission
on Behalf of the Yukon River Basin Committee

9 March 1984

Prepared by
Monenco Consultants Pacific Limited
1199 West Pender Street
Vancouver, British Columbia
V6E 2R1

This report was funded by the Yukon River Basin Committee under the terms of "An Agreement Respecting Studies and Planning of Water Resources in the Yukon River Basin" between Canada, British Columbia and Yukon. The views, conclusions and recommendations are those of the author and not necessarily those of the Yukon River Basin Committee, the Energy Work Group, the Government of Canada, the Government of British Columbia or the Government of Yukon.

This report was prepared as a background paper for the Energy Work Group. Please refer to the Final Study Report for the views of the Yukon River Basin Study Committee.

SUMMARY

A study of the importance of water storage to the Yukon hydroelectric potential has been carried out and has demonstrated the value of adequate flow control for economic hydro development.

Storage projects can often be developed for multiple use of the water resource, and most have some non-power benefits for other water users.

Storage is seen as particularly important in the North, with a high winter demand for power coinciding with the low natural stream flow. On rivers without headwater storage economic hydro development will not normally be practical. While some means of reducing the required storage exist, for a small system these are at present only long term future prospects, or temporary short term measures.

In a comparison of artificial reservoirs produced by impounding in river valleys or the use of augmented lake storage, the latter is seen generally as a better alternative, both with regard to cost and environmental impact.

Reservoir clearing costs can be as much as 25% of total project cost and are significantly affected by the clearing standards to be set by regulatory authorities. Guidance from such authorities is necessary to allow proper site selection between projects having large reservoirs requiring clearing, and those needing only minor clearing.

A multi-discipline team approach is seen as the proper method of resolving problems of project compatibility with socio-environmental concerns. This should be initiated with the conceptual design of the project. The adversary system has serious weaknesses with respect to this approach, and also in facilitating quick and proper resolution of the development vs socio-environmental status quo conflict.

A study of the non-power benefits, and of mitigation and enhancement possibilities of each project is suggested, this to be carried out in addition to the environmental impact study.

Follow up socio-environmental studies on completed projects are needed to improve prediction for future projects and assist regulatory decisions.

Restricted headwater lake storage to near historic lake levels would reduce the power potential of Upper Yukon main stem power projects by about one third, or for the Yukon River as a whole by only about one fifth, thus retaining the major portion of the potential despite this limitation of lake level variations to reasonably acceptable levels.

Further reductions in potential can be expected resulting from other environmental concerns, and studies are required to determine the realistic hydroelectric potential of the Yukon main stem, and of the Yukon-Taiya and Yukon-Taku projects with acceptable socio-environmental impacts.

Protection of the option to regulate to at least historic range on existing lakes is most important to Yukon Basin development.

Refer to Sections 7 and 8 for more detailed Summary, Conclusions and Recommendations.

STORAGE AND THE YUKON HYDROELECTRIC POTENTIAL

TABLE OF CONTENTS

		PAGE
	SUMMARY	(i)
	TABLE OF CONTENTS	(iii)
	STUDY TERMS OF REFERENCE	1
1.	INTRODUCTION	4
2.	WATER STORAGE AND FLOW CONTROL	5
3.	FLOW CONTROL FOR HYDROELECTRIC DEVELOPMENT	9
	3.1 Seasonal Flow Patterns	10
	3.2 Cyclical Flow Variation	12
	3.3 Hydro Power and Storage	13
	3.4 Alternatives to Storage	17
	3.5 Summation	20
4.	LAKE STORAGE OR MAN-MADE RESERVOIRS	21
	4.1 Cost Comparison	21
	4.2 Socio-Environmental Considerations	22
	4.3 Reservoir Clearing	24
5.	SOCIO-ENVIRONMENTAL FACTORS	27
	5.1 Environmental Impacts	27
	5.2 Multiple Use	30

		PAGE
6.	STORAGE AND THE YUKON HYDRO POTENTIAL	33
	6.1 Storage and Tributary Development	33
	6.2 Yukon River Main Stem Potential	34
	6.3 Factors Reducing Hydro Potential	37
	6.4 Storage Scenarios and Power Potentials	38
	6.5 Yukon River Development with Reduced Storage	42
	6.6 Yukon-Taiya and Yukon-Taku Potentials with Reduced Storage	43
	6.7 Relative Importance of Upper Yukon Lakes for Storage	44
7.	SUMMARY AND CONCLUSIONS	45
8.	RECOMMENDATIONS	51

APPENDICES

Appendix A - Water Storage Reservoirs

Appendix B - North Saskatchewan River Ice Study

Appendix C - Dams and the Environment

Appendix D - Letter from B.C. Hydro to D.R. Duguid - 25 August 1983

Appendix E - Bibliography and References

TABLES

TABLE	
3-1	Yukon River Flow Extremes
3-2	Cyclical Flow Variations - Three Yukon Rivers
6-1	Dependable Power vs Storage for Three Medium Sized Projects
6-2	Yukon Main Stem Firm Capacities for Various Storage Scenarios
6-3	Limitation of Prime Power Potential by Reduced Upper Yukon Storage
6-4	Upper Yukon River Lake Storage

PLATES

PLATE	
3-1	Typical Regulated and Unregulated Flows of the Upper Pelly River
3-2	Dependable Flow Curve at Marsh Lake Outlet
6-1	Location of Potential Sites on the Yukon River
6-2	Schematic Plan of Yukon River, Lakes and Reservoirs

STUDY TERMS OF REFERENCE

Monenco Consultants Pacific Limited has been retained by Northern Canada Power Commission to carry out a study on the importance of storage and flow regulation to the hydroelectric potential of the Yukon. The Terms of Reference and Scope of Work are given herewith:

Terms of Reference

The purpose of the study is to identify the significance of man-made reservoirs and augmented natural lake storage to the development of the Yukon River Basin's hydro potential.

The study will demonstrate the critical importance of storage and flow regulation to northern hydroelectric development.

The study will draw attention to the possible conflicts with other water users and also to any non-power benefits which can result.

Scope of Work

The study will examine the options of control of existing lakes as compared with creating man-made reservoirs in river valleys, and review alternative standards of reservoir clearing, which is often the major cost of reservoir creation.

The study will compare, as far as possible from available information, the principle Yukon River headwater lake storages and potential man-made reservoirs for cost-effectiveness in increasing energy production, with recognition of trade-off issues with other uses of water and land areas affected. From this evaluation, the most important lakes and reservoirs for the purpose of development of the hydro potential would be identified.

The study will demonstrate the principles established, by application to the mainstem Yukon River plants identified in the original Yukon River Basin Study of 1962, and provide a revised power potential based on possible reduction in headwater storage. Comment would be made on the need to study the Yukon-Taiya and Yukon-Taku diversion schemes with lesser storage provisions and so reduced environmental impact.

The study will comment on the complexity of the effect of interconnection with the British Columbia Hydro and Power Authority system on the need for storage in the Yukon.

The report section will be quite brief, between 25 and 50 pages.

It is assumed that necessary input on Yukon River storages and regulated flows will be provided from the Hydrology Work Group, and a comment on the effect of system interconnection on required storage from B.C. Hydro will be available.

The Scope of Work is to be taken as indicated only, with the emphasis given to each section to be at the Consultant's discretion. The depth of study will be tailored to the budget which will not be exceeded without written permission from NCPC.

The budget for the study is $25,000.

1. INTRODUCTION

The need to store essentials such as food, fuel and water is as old as civilization. Furthermore, wildlife, such as beaver, squirrels, and some birds and insects, survive the lean cold seasons by their ability to store, while others must hibernate or migrate. Man has greatly reduced the consequences of drought, famine, and the elements using this strategy. In fact it was likely a major factor in freeing him from the rigours of a nomadic existence. The quality of life he has achieved owes much to his ability to hold surpluses from times of plenty to tide him over periods of scarcity.

Creation of reservoirs to store water can be traced into prehistory and this together with many other aspects of water storage is discussed in Mr. J.K. Sexton's paper, Appendix "A". He cites the example of perhaps the earliest storage dam in Egypt some 4,500 years ago. It is this control of the water resource that will form the subject of this report.

2. WATER STORAGE AND FLOW CONTROL

The beaver demonstrates in a remarkable way the many advantages of storage on rivers. The construction of beaver dams provides these animals with protection from the effects of winter, which could expose them to predators and make their food supply inaccessible. It also increases the shoreline from which they can reach trees for food supply.

It is even more interesting to note that habitat for fish and some wildlife is improved and enlarged both in the beaver ponds created and also by the more even flow pattern downstream. This normally shows increased minimum flows while reducing damaging flood erosion and siltation. It is true that, in some cases, beaver dams, like those of man, may hinder fish migration, but this is normally a minor factor.

Natural lake storage also provides benefits to fish and wildlife. The outlet of large lakes often provides an ice free area of great importance to waterfowl and a relatively well regulated river flow with ample food supply as a fish habitat.

The advantages of man-made impoundments can apply to many resource uses such as fish, waterfowl, consumptive use by man and industry, dilution of pollution and, of course, hdyroelectric power.

One example is the use of control dams such as that regulating the flow of the Big Qualicum River in British Columbia for the benefit of a salmon hatchery and spawning channel complex. Here, both the flow and temperature is controlled for optimum benefit to the hatchery, and damaging floods are prevented or reduced both by tributary diversion and the effect of the reservoir.

Many projects are initiated based on benefits for more than a single resource use. An example of such a multiple use development producing power benefits, together with pollution alleviation and fisheries benefits, is provided by the Brazeau and Bighorn power and storage projects on the North Saskatchewan River drainage in Alberta. This development and its non-power benefits are described in Appendix "B", but in essence it provides a four-fold increase in the minimum winter flow through Edmonton and a 50% increase in dissolved oxygen in the river downstream of Edmonton. Sport fishery benefits including a new trophy-type sport fishery in the Brazeau/Big Bend forebay canal and improvement in the quality of sport fishing in the North Saskatchewan River, which has now a much reduced silt load downstream of the Bighorn reservoir (Ref. 3).

Some projects initiated on a single use concept have secondary benefits to other resource users. For example, close to home, the non-power benefits of the Whitehorse Rapids hydro plant with its storage dam at the outlet of Marsh Lake include:

- A convenient source of potable water for the Whitehorse water supply system.

- Increased winter and spring river flows through Whitehorse, to about double the unregulated flows, without which the level of pollution from the sewage treatment system effluent would be much more severe.

- A marked decrease in winter flood levels through Whitehorse by reduction in the formation of frazil ice, this despite increased winter flow. As pointed out in (Ref. 7), river levels prior to the construction of the

hydro plant reached as high as Elevation 634 m, the level at the White Pass railway depot in downtown Whitehorse.

- The constant level Schwatka Lake which is utilized for scenic boat trips and as a convenient float plane base.

- The hydro plant itself is a tourist attraction with its impressive summer spillway flows, the salmon ladder with viewing station, and in future the new hatchery.

- Provision of canoe landing and portage facilities, with hiking trails along river and lake.

While some of these benefits result from the hydro plant structures rather than the storage dam, the combined effect is normally considered.

Flood control is another major benefit of storage reservoirs, but their use for this purpose often means operation in a manner not compatible with obtaining maximum power or other water use benefits; i.e., holding reservoirs part empty prior to flood peak. The magnitude of these benefits, however, can be gauged for example by the lump sum payment of $69 million[1] made by U.S.A. to Canada in 1973 for flood control provided by the Columbia River storage developments under the Treaty provisions. In terms of 1983 dollars this is more than $200 million. In 1983 a potential flood flow capable of raising river levels 8 ft. above flood stage at Portland, was reduced to 60% of the unregulated peak (Ref. 2).

---

[1] Initial payment only; final payment significantly higher.

Provision of water for irrigation is the prime benefit and reason for construction of many storage dams. However, north of 60°, this has so far not been a factor.

In parts of the continent where lake based recreation facilities are deficient or absent, man-made reservoirs can provide much needed recreation and tourism benefits. To a lesser degree, this can also apply to the North.

A dam and spillway with spectacular flows can become a tourist attraction, such as is the case with the water supply Cleveland Dam in Vancouver, and with many other major projects.

The foregoing summary of the multiple use possibilities of storage projects and the non-power benefits of hydroelectric plants and storage is given to draw attention to the often overlooked aspects of such developments, and it should not be taken as suggesting that there are not accompanying costs which are considered later in this report.

The need for flow control for hydro power development and the associated benefits are considered in the following section.

3. FLOW CONTROL FOR HYDROELECTRIC DEVELOPMENT

Modern society depends to a remarkable extent on electric power, both for domestic and for industrial use. The degree of this dependency dictates that, to an equally remarkable extent, electric power must be reliable and dependable in meeting whatever demands are made on it.

There is little need to remind readers how much the domestic scene depends on continuous power supply, particularly if they have experienced any lengthy outages; fortunately, rare in our society. Public services such as hospitals, water supply, and sewage treatment are also heavily dependent, although usually with standby provisions. Industries such as mines, mills, smelters, etc., must have a dependable supply and adequate standby is normally not practical.

Power demands vary from hour to hour during the day, and from month to month during the year. In northern climes, where heating is a significant factor, highest demand is around mid-winter. Peak usage during the day usually coincides with supper time. This peak demand can normally be handled by a small amount of storage provided from the plant forebay which can be replenished in the night time during off-peak hours of low demand. Where conventional peak handling capacity is not adequate, costly pumped storage plants may be resorted to. Many of these are under construction in the U.S.A. at costs in the order of $1,000 per kW capacity.

The very much larger storage requirement to match the seasonally varying power demand with a water supply which varies both seasonally and cyclically, is the subject of this study.

3.1 Seasonal Flow Patterns

In northern latitudes, the problem of storage is particularly severe because river flows are low when power demand is highest. The power available from a hydro plant is directly proportional to the flow, so that higher flows are required to meet increased winter power consumption. However, the low flow months, normally December to April, almost coincide with the high load period.

To provide a reasonable control of river flow, a reservoir volume is required which can contain more than half of the annual flow. There are some rivers, the upper Yukon River is one, which are blessed with substantial natural lake storage. This greatly reduces the seasonal flow variation by holding back part of the flood runoff, augmenting flows during the winter. Such rivers require less artificially controlled storage.

An outstanding example of large natural storage in the North is Great Bear Lake in the Northwest Territories, which provides Great Bear River with a ratio of extreme maximum to minimum flows of only 4 to 1, and where, over the years, the average flow of the lowest month (April) has been over 80% of that of the highest month (September).

At the other end of the scale are the Firth and Babbage Rivers on the Yukon North Slope, which have virtually no headwater lake storage and have no recorded flow at all during four or five winter/spring months.

Table 3-1 demonstrates the extremes of flow recorded during the period of record for three Yukon rivers, ranging from one with no natural regulation (Firth), through moderate natural regulation (Pelly River), to the relatively well regulated Upper Yukon River case.

TABLE 3-1

Yukon River Daily Flow Extremes
(cubic meters/second)

	Minimum	Maximum	Average	Max/Min Ratio	Years of Record
Firth River	0 (Jan-Apr)	773 (May)	39	infinite	3
Upper Pelly River (3)	6 (Mar)	2,000 (June)	187	333	15
Upper Yukon River (4)	33 (May)	646 (Aug)	240	20	36

NOTES: (1) Source Historical Streamflow Summary to 1979, Water Survey of Canada.
(2) Figures rounded for simplicity.
(3) Measured at Ross River.
(4) Measured at Whitehorse.

The flows in Table 3-1 are the absolute extremes experienced over the years of measurement records. Accordingly, they reflect not only the seasonal variation, but also the cyclical variation between wet and dry years discussed in the following pages.

From the table, it will be clear that naturally well regulated rivers, such as the Upper Yukon, have a relatively lower requirement for storage to provide adequate regulation as compared to rivers such as the Firth.

3.2 Cyclical Flow Variation

In addition to the variation of flow with the change of seasons, there is also a variation of the total annual volume of water running into each river from its drainage basin from one year to the next. This cyclical variation is not as wide as the seasonal variation, and the wet year to dry year ratio is, generally, about 2 to 1, although it may range in the north from about 1-1/2 to 1 to 3-1/2 to 1.

It would be necessary to store water over several years to effectively even out cyclical variation and provide the maximum dependable flow. For the majority of sites this might not be possible, nor, in some cases, would the required reservoirs be environmentally acceptable. However, on some rivers blessed with large storage potential relative to inflow, dependable flows close to the long term average flow may be obtained. The Aishihik Hydro development is on such a river.

Table 3-2, below, shows a comparison of cyclical flow variation for three rivers on which there are existing or projected hydro projects.

TABLE 3-2

Cyclical Flow Variations - Three Yukon Rivers

	Average Annual Flows (cubic meters/second)		Ratio	Number of Years Recorded
	Driest Year	Wettest Year		
False Canyon Frances R.	132	186	1.4	14
Whitehorse Rapids Upper Yukon R.	186	317	1.7	36
Aishihik Aishihik R.	7	25	3.8	27

Source: Historical Streamflow Summary to 1979, Water Survey of Canada.

The importance of carry-over storage to the Aishihik project with such a wide cyclical river flow variation is clear, while the advantage to the other projects is seen to be far less.

3.3 Hydro Power and Storage

Most hydro plants, except some on naturally very well regulated rivers, must use storage, either by drawdown of the reservoir formed by the power dam, or provided by a storage dam or control structure at some suitable upstream location, or by both. This is the case, with few exceptions, for "mini" projects of a few megawatts capacity, up to major developments with hundreds of megawatts output.

There are two types of flow control projects; the combined power/storage dam and the simple storage structure. The integral power/storage project eliminates the need for a separate storage dam but may have to depend on a lower dependable flow, and generate with a falling head as the reservoir is drawn down.

The upstream storage structure can be located most favourably relative to topography to efficiently provide adequate storage, but may add substantially to the project cost.

It is not the intention in this study to examine the technical details of hydro electric generation or systems. However, it is necessary to draw attention to some basic aspects.

.1 The amount of energy that can be generated at a plant is directly proportional to:

- the water level difference (head) between intake and tailrace; and

- the flow which passes through the plant.

i.e. Power = K x Q x H
where K is a constant incorporating efficiency.

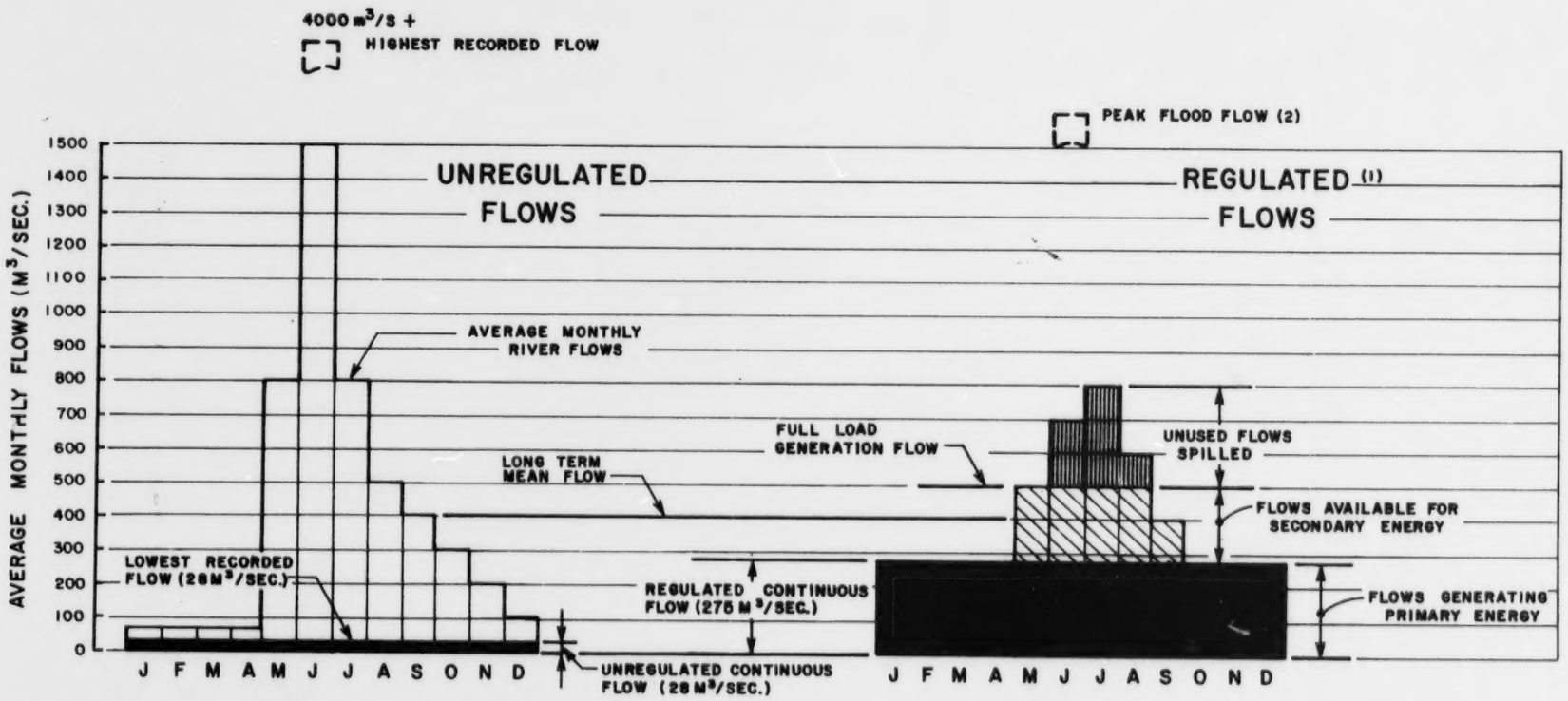
.2 Variation of the available flow means that the minimum regulated flow will determine the dependable rate of generation; that is, the power output that can be produced continuously throughout the year, including the driest year. Generation capacity about 60% in excess of this might be installed to meet periods of high demand and provide reserve capacity.

.3 While more kW hours can be produced from a plant than that determined by the dependable flow, normally the latter is the chief factor determining the size of the plant and the level of revenue it will generate, or more generally, the project benefits.

.4 As shown in Plate 3-1, while storage cannot increase the average annual flow, it can change the distribution in time so that more of it is usable. Flow in excess of what can be taken by the turbine installation must be discharged over the spillway and provides no power. Furthermore, since the high spring/summer unregulated flows occur at a period of lower demand, the power which could be generated in excess of the level of dependable continuous generation, so-called secondary energy, often cannot be used.

.5 At a given site, the cost of a hydro plant does not increase proportionally with increase in flow and generating capacity. A major proportion of the cost is in the dam, spillway, diversion works, etc., which are in effect fixed costs virtually independent of the installed generating capacity. The cost of water passages, powerhouse and generating equipment, however, do increase with plant capacity. The combined cost shows decreasing incremental costs with increasing generation capability, when the latter is made possible by increased dependable flow from storage.

.6 Dependable flow and firm power increase with increasing storage, but with diminishing returns, as shown on Plate 3-2. As storage is increased there may also be some reduction in mean flow due to evaporation loss.



NOTES

1. SUBSTANTIAL BUT NOT OPTIMUM STORAGE IS ASSUMED
2. PEAK FLOW INDETERMINATE DEPENDING ON RESERVOIR OPERATION

PLATE 3-1

NORTHERN CANADA POWER COMMISSION

YUKON HYDRO STORAGE STUDY

TYPICAL REGULATED AND UNREGULATED FLOWS OF THE PELLY RIVER

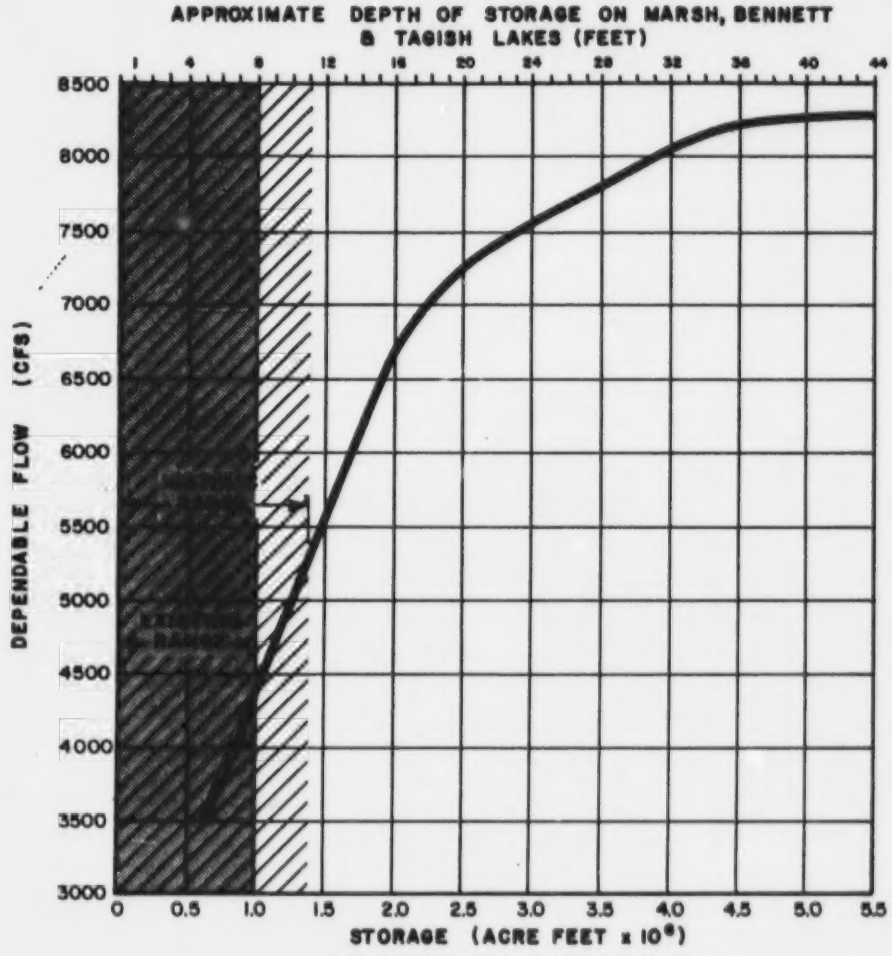


PLATE 3-2

NORTHERN CANADA POWER COMMISSION

YUKON HYDRO STORAGE STUDY

DEPENDABLE FLOW CURVE AT MARSH LAKE OUTLET

.7 There are some run-of-river projects where the system provides "firming" generation from thermal plants or other storage rich hydro plants, and close to the average flow may be developed.

It should be noted that the terms "primary", "prime", "firm" and "dependable" used interchangeably in the report with "power", "capacity", "energy" or "output" should be taken to relate to continuous generation at a constant level, utilizing the dependable regulated flow which can be maintained through the critical low water period.

From the foregoing, it will be seen that, provided the cost of obtaining upstream storage is not prohibitive, increments of storage will increase benefits much more than costs, at least up to a well regulated level. Provision of upstream storage very often makes a financially unattractive project into a practical development. In terms of optimizing the use of the water resource, storage may increase the power benefits several times (Plate 3-1).

Where additional storage can be obtained with minimal environmental cost, there is a benefit in that the increased plant output may eliminate or defer the need for another hydro plant, with its associated impact, to meet the load.

It should be stressed that the foregoing discussion on the need for storage applies primarily to individual hydro plants or to small connected systems, such as Whitehorse/ Aishihik, which are not interconnected to a major power system. Such a mature system, where low cost coal-fired thermal and even nuclear plants may provide the base load, has less need for seasonal storage. However, an example of the magnitude of power benefits to a major system is the amount

paid to British Columbia for flow regulation from the three Columbia River storage projects. A sum of $273 million[2] was paid by the U.S.A. in 1964 for the benefits over a 30 year period. This would be about $1,000 million 1983 dollars or, since inflation in power costs has outpaced dollar devaluation, perhaps double this figure in current value of power. This power benefit was of course, in addition to the flood control benefit noted earlier in Section 2.

3.4 Alternatives to Storage

The most direct alternative to water storage is provision of an alternative energy source to provide power when flows for the hydro plant are inadequate. Practically, this means thermal generation, most often diesel generation in the North. The problem is that this in effect means providing two powerplants instead of one, a hydro plant primarily for summer/fall operation, and a diesel plant for winter/spring operation and for use in low water supply years. Energy from both sources would be very costly from underutilization of plant, and also, for the diesel plant, from the high cost of imported fuel. In most cases, this solution is impractical on a long-term basis, but has been used where standby diesel plant is available as a short-term solution.

Another possibility for reducing storage requirements is interconnection with another power system, such as that of B.C. Hydro. Particularly if such a neighbour system serves an area with different load and runoff patterns, and has large storage capability, the benefits of interconnection can be great. The support of reserve capability is mutually

---

2 Initial payment only; final payments were significantly higher.

beneficial to interconnected systems and, provided the cost of the necessary transmission lines are not too great, such interconnection is to be supported.

The feasibility of an interconnection between NCPC and B.C. Hydro systems has been examined in a study by B.C. Hydro (Ref. 15) and the terms on which storage benefits could be provided to Yukon are described in a letter from B.C. Hydro and included with this report as Appendix D.

From these sources, it would appear that interconnection could reduce storage requirements of the Yukon, but that the degree and certainty of this reduction, the associated price of such substitute storage, and when an interconnection might become practical, are all unknown at this time.

With B.C. Hydro's Stikine or Liard project, a necessary prerequisite to interconnection, delayed into the 21st century, and with a substantial Yukon load of the order of 100 MW or more necessary to make it practical, it seems that such substitute storage is unlikely to affect the next hydro project or the one after that.

Another possible but presently uncertain prospect is an interconnection with Alaska.

A disadvantage of such storage alternatives is that they substitute imported fuel or facilities instead of developing an indigenous Yukon Basin resource, and this may be judged undesirable by some.

Interconnection with a project on the Great Bear River, if this is developed in the not too distant future,

would certainly add an exceptional storage to the combined system. Again, this would require the emergence of substantial loads, both to initiate one of the major Great Bear projects and to justify the cost of the interconnection. However, considering that complete regulation of a river with a 600 MW potential may be obtained with an increase of natural lake variation of just over one foot, the socio-environmental cost of this system storage is likely to be low and the power benefits high.

There is of course another substitute for storage and that is some form of rationing of electric power. While this strategy is resorted to in some underdeveloped countries and also, to meet emergency conditions on many power systems, such load shedding and brown outs are not seen as a practical option. This is particularly so in the north, where heat, light, and power for appliances in the home, and industrial plant supply must at all costs be maintained throughout the winter and also in dry years. In fact such a strategy simply transfers the burden of providing substitute generation to the home or plant and is not seen as an acceptable alternative.

Finally, as a means to minimize storage requirements, where there is a choice between early development of naturally well regulated rivers such as the Yukon River or those without natural lake storage, use of the former will reduce artificial storage needs. For example the Mid-Yukon Development (Phase 1 and 2) on the Yukon River near Carmacks requires no added upstream storage for 240 MW installed capacity.

3.5 Summation

In summary, the storage reservoir is the means by which a seasonally varying and cyclically uncertain water supply can be made to provide a reliable and continuous power supply to meet a varying demand. Without it, many potential hydro projects would be uneconomic. If there is not adequate storage, only a fraction of the available water power will be produced, the reliability of the system will be lower, and the cost of energy higher. This applies to all sizes of projects from "mini" to "mega".

Storage alternatives available do not appear to offer a practical, long-term, and low cost substitute to storage reservoirs for many years to come.

4. LAKE STORAGE OR MAN-MADE RESERVOIRS

Flow control for some projects can take advantage of existing lakes, with levels varied by an outlet control structure to benefit downstream users, including power plants. On other projects, new reservoirs must be created by storage dams. Selection of projects for development may depend to a significant extent on the relative costs and environmental impacts of these storage alternatives where they exist.

The evidence suggests that, where adequate storage can be obtained on existing lakes, this is the better option both from the cost and environmental standpoint. Where control of a natural lake within the historic range of levels provides adequate storage, this preference is particularly strong.

A modification of augmented lake storage, which is practical at a few sites with minimal negative input, is the use of bottom storage by improving the lake outlet to obtain a slightly lower minimum lake level, thus minimizing the need to raise the maximum level.

4.1 Cost Comparison

The necessary height of a storage dam or control structure is determined by the volume of water to be stored and controlled, and thus by the surface area of the reservoir. A large natural lake will require only a small drawdown and, thus, a low control structure, to provide substantial storage. The often smaller area of an artificial reservoir limited by the steepness of the river gradient will

require a greater drawdown and accordingly a greater dam height to provide the same storage. It therefore follows that the higher dam and spillway facilities required for many reservoirs will be more costly than a lake outlet control structure.

There is another factor which can be even more compelling and that is the cost of reservoir clearing which may be very high for a storage formed by flooding in a river valley (10-25% of hydro project capital cost). In comparison, clearing may not be required or be relatively minor around the shores of an existing lake.

As an example of the magnitude of this cost, full clearing of a reservoir the size of the Marsh/Tagish/Bennett Lake system controlled by the Marsh Lake dam, could cost today as much as $165 million.

A negative factor for utilizing existing lakes for storage is that mitigation costs could be incurred in respect of the use of lake shores by people and wildlife.

In the balance, when considering storage only schemes, the cost advantage in most cases will be with augmented storage from existing lakes. For dams having both storage and power facilities, the comparison is more site specific and less subject to such generalization.

4.2 Socio-Environmental Considerations

Comparing augmented lake storage with reservoir storage from a socio-environmental viewpoint is more complex and certainly more dependent on site specific factors.

Accordingly, it is not appropriate to attempt to make comparisons for each possible impact, and instead only two or three major factors will be considered.

First there are those factors which appear negative for reservoir storage.

Reservoirs normally have greater dam height and depth of impoundment. From a fish migration standpoint, the higher the dam, the greater the problem of fish migration upstream and downstream, also in some cases the more extensive the river spawning areas affected.

Associated with such reservoirs in some cases is a large drawdown range with such problems as bank stability and the negative aesthetics of exposed flooded areas reducing recreation potential.

The magnitude of land area flooded to create reservoirs compared with the much lesser flooding required for augmented lake storage is a negative factor for forestry, agriculture (if any), wildlife habitat and other considerations.

All these foregoing appear to indicate that the use of augmented existing lake storage should be favoured from the socio-environmental standpoint.

On the other hand, for augmented lake storage, impacts on the use of existing lake shores by communities and wildlife would be negative factors. Traditional native peoples use of shoreline is often involved. It is to be noted that a longer shoreline is likely to be involved than in the man-made reservoir with greater drawdown.

In the balance, it is judged that the control of existing lakes as close to the historic range of lake levels as possible will be found in the majority of cases to be the more desireable alternative.

4.3 Reservoir Clearing

The high cost of clearing has been noted in 4.2 and a unit cost of $3,000 per hectare has been used in recent Yukon hydro studies for normal clearing and disposal. On the assumption that all flooded areas are fully cleared, and the trees and brush are burned or buried, the tabulation on the following page shows the reservoir and clearing areas with clearing costs and the proportion of the total capital cost these represent. Since this can be as high as 25%, it is a major component of the resulting power cost.

Project	Capacity MW	Reservoir Area Hectares	Clearing Area Hectares	Project Cost* $M's	Clearing Cost $M's	% of Project Cost
Low Granite Canyon	120	26,400	28,800	305	76	25%
High Granite Canyon	254	51,000	-	629	160	25%
Mid Yukon I/II	240	15,200	10,500	447	36	8%
Hoole Canyon	40	9,800	6,000	146	24	16%
Slate Rapids	42	14,400	10,200	165	39	24%
Ross Canyon	30	7,300	6,150	181	25	14%
False Canyon	58	21,000	8,650	252	36	14%

Note: Costs include overheads.

* Including reservoir clearing.

A normal clearing standard of cut and dispose is assumed for the tabulation whereas clearing standards could vary all the way from one extreme - no clearing, to the other extreme which calls for full cut and disposal with removal of stumps and all organic cover. Clearing cost could vary from zero to perhaps 50% more than the clearing standard assumed.

By examination of the table, it is clear how the standard of clearing decided upon by the regulatory authority could significantly affect project capital costs. It can also be seen that, since the effect of clearing costs on total cost varies widely from project to project, the relative economic

attractiveness of alternative sites could be changed by the standard of clearing required. With no prior guidance, a project may be chosen, adequately studied, and presented to the Water Board for a license, only to find that clearing required is not as assumed, which would make an alternative site a better choice.

Furthermore, considering the tens of millions of dollars of additional costs which might have to be borne by the Yukon power consumers, it is expected that the regulatory authority will react properly to the need for a careful decision by initiating studies to determine the most appropriate clearing standard. The factors to be taken into account in setting reservoir clearing standards are many and it is not necessarily true that environmentally the more complete the clearing, the better. For example, in some circumstances uncleared areas may be required for fish habitats. Clearly, the time required to study and establish clearing standards, and a further delay if this changes project selection, can seriously retard project initiation with resulting higher electric power costs.

This suggests that early study of clearing standards should be initiated on a general or regional basis to provide guidance to assist project selection.

5. SOCIO-ENVIRONMENTAL FACTORS

The possible effects of storage projects on communities and the environment have been documented in numerous papers and publications and of course in environmental impact statements.

A summary of possible environmental effects of dams prepared for the International Commission for Large Dams is included with this report as Appendix C. It will be noted that this deals with conditions in the tropics as well as in temperate and northern areas. It has been included instead of repeating here yet another comprehensive list of all possible effects. In this section of the report only some environmental factors likely to be of major importance in many northern projects are discussed. Most of the socio-economic factors are too site specific for such generalization.

5.1 Environmental Impacts

The major environmental changes to the areas brought about by a storage project are normally:

1) The creation of a substantial reservoir with a varying water level, or the control of the levels of an existing lake.

2) Regulation of the downstream flows tending to even out the seasonal and cyclical variations.

3) Restriction to the migration of fish and navigation of boats past the storage structure.

Clearly many water use interests may be affected, in particular fisheries, tourism, wildlife, recreation, forestry, and native and other shoreline communities. Change will occur, but not always negative change, particularly if suitable mitigation measure are possible.

Considering the major changes listed above in the broadest sense:

1) In man made reservoirs, land areas are replaced by water areas, and if such land is more valuable as a resource, then this is a loss that cannot be avoided. River habitat is replaced by lake habitat and this may be a cost or a benefit depending on alternatives available in the area. Loss of wildlife habitat in low lying areas may be a major concern.

   In the case of regulating existing lakes within historic limits and causing no flooding but a changed lake level pattern, lake shore use and facilities may be affected; also water fowl and some fur bearers.

   Mitigation and enhancement measures which may be practical include:

   - tourist camps and recreational facilities on the reservoir which would be cleared to appropriate standards. Shoreline protection where required.

   - fish stocking and management for the lake fishery offsetting flooding of spawning areas.

   - opening up non-productive tributary spawning streams.

- control of lake levels where possible to favour water fowl and aquatic fur bearers, or control of levels in dyked areas for the same purpose.

2) The moderation of seasonal and possibly cyclical river flow variation should most often be beneficial to water users, including man, fish, and other aquatic wildlife. However, in some cases, including heavily sediment laden streams, negative impacts such as erosion may occur. At other sites, reduction of silt content may be beneficial to fish. Changes in water temperature and quality might present problems.

Mitigation measures are site specific, but may include erosion protection for the river, or low level discharge of sediment laden water. Temperature control from the reservoir may be possible, and flow control within limits to avoid downstream problems. Spillways can be designed to avoid detrimental nitrogen entrainment. Benefits which may accrue even without deliberate flow manipulation are reduction of egg losses due to freezing of exposed river bed or by silt blanketing, and of fry entrappment in small pools with dropping river levels.

3) Restriction to the passage of migratory fish is a major problem for dams above 30 metres in height.

Restriction to river navigation where present can also be a major factor.

Mitigation for upstream and downstream migrants may be quite complete on low dams such as simple control structures, where fish ladders or other fish pass facilities are effective and where relatively low

velocity spillways are present. For high head projects mitigation measures would also include hatcheries, spawning channels, or similar facilities, the cost being dependant on the number of fish involved.

In a similar manner the problems of mitigating navigation restriction depends on both the head at the dam and size of boats to be handled. Suitable mitigation measures range from very expensive locks to simple boat transfer arrangements.

These broad generalizations by no means cover all concerns and are not universally applicable to all sites as previously noted.

5.2 Multiple Use

The basic problem, assuming a given project has been chosen as the most beneficial to society, is to achieve the maximum of benefits over costs with a multiple use concept of the project. By means of suitable design, including mitigation of negative impacts, power benefits and associated non-power benefits should be the greatest possible with respect to financial and socio-environmental costs. To use a simple equation the net benefit to be maximized is:

Net Benefit of Storage = (Power benefits + Non-Power Benefits) less (Total Project Costs + Residual Socio-environmental Costs)

It is of course recognized that some of these costs and benefits cannot be accurately determined. However, with some judgement, rational approximations can be made and there is no excuse for ignoring and omitting factors on these grounds.

It is not difficult to understand that to come close to the optimum solution a multi-disciplinary team approach to the problem is necessary. Biologists must be on this team as well as engineers, and all must be dedicated to the same goal, to design a project with the highest possible net benefit to society.

The adversary approach, with each competing interest group attempting to further their particular resource use at public hearings before a quasi-judicial regulatory body, has not been an unqualified success. It is undoubtedly time consuming and costly like any complicated litigation, and it often results in long delays instead of prompt decisions. It also produces polarization of views and confrontation tactics which make the necessary compromises more difficult. It can be hoped that a better system will evolve for resolution of resource use conflicts and for proper selection of the best multiple use solution.

Under existing conditions one suggestion can be made to ensure that multiple use receives the proper consideration and mitigation measures are fully investigated. This is to commission a multiple use study by a multi-disciplinary team to examine the non-power benefits of each project and the mitigation and enhancement measures which may be possible. The goal of the study team, which will include hydro engineering designers, will be to see what is practical in reducing socio-environmental costs and increasing non-power

benefits. This would be carried on concurrently with the environmental impact study but by a separate group who would however, have access to the baseline data and project impacts anticipated.

An invaluable input to both studies would be follow up studies on the observed impacts of already constructed projects, which could be compared with the predictions made to the licencing authorities. These, unfortunately are all too seldom carried out. They could provide input data and guidance for future development and assist regulatory authorities in their decisions.

6. STORAGE AND THE YUKON HYDRO POTENTIAL

The hydro potential of the Yukon Territory if fully developed would allow installation of about 10,000 MW of generating capacity.

Dependable flows, assuming full storage where available, would support continuous generation of about 6,000 MW.

This potential would be reduced by the elimination of projects judged unacceptable due to socio-environmental concerns, and reduction of storage and head on other projects for the same reason.

About one half of the total Yukon hydro potential is on the Yukon River main stem and the reduction of this which would result from lower allowable storage is addressed later in this section of the report. The main stem plants are generally large and most will not be developed in the near future. They have the benefit of natural regulation from the huge head water lakes which reduces their dependence of man made storage.

6.1 Storage and Tributary Development

Smaller plants on tributary rivers are likely to be developed sooner then those on the Yukon River, and these often have little natural regulation. Provision of storage is critical and Table 6-1 shows reduction in power potential if no storage were permissable for three projects recently investigated as likely for early development.

TABLE 6-1

Dependable Power vs Storage
for Three Medium Sized Projects

Project	Prime Capacity in MW Supported by Dependable Flow			
	Full Regulation MW(1)	No Regulation MW	Practical Regulation MW	% of (1)
Hoole Canyon	39	1	25	(64%)
False Canyon	55	5	35	(64%)
Ross Canyon	26	1	18	(69%)

From this table it can be seen that about 65% of the long term mean flow can be regulated to provide continuous power with available storage, while without such storage, dependable power of only 5% to 10% of the firm capacity is possible. This is the extreme theoretical case where not even the plant forebay provides any regulation.

6.2 Yukon River Main Stem Potential

In 1962, the Water Resources Branch of the Federal Department of Northern Affairs and National Resources produced a report entitled the Yukon River Basin Study. The study identified a series of potential hydroelectric sites on the Yukon River from the Alaska boundary to the headwater lakes,

and on the main tributaries including the Teslin, Pelly, and Stewart Rivers. The main stem sites are shown on Plate 6-1. The sites downstream of the Pelly River confluence and those on the Pelly and Stewart tributaries have been designated as in the Lower Yukon basin, and those upstream of the confluence, on either the main stem or upstream tributaries, as in the Upper Yukon basin (Plate 6-2).

The 1962 study investigated two development scenarios:

(1) A "Major Plan" of optimum development assuming no diversion from the headwaters of the river.

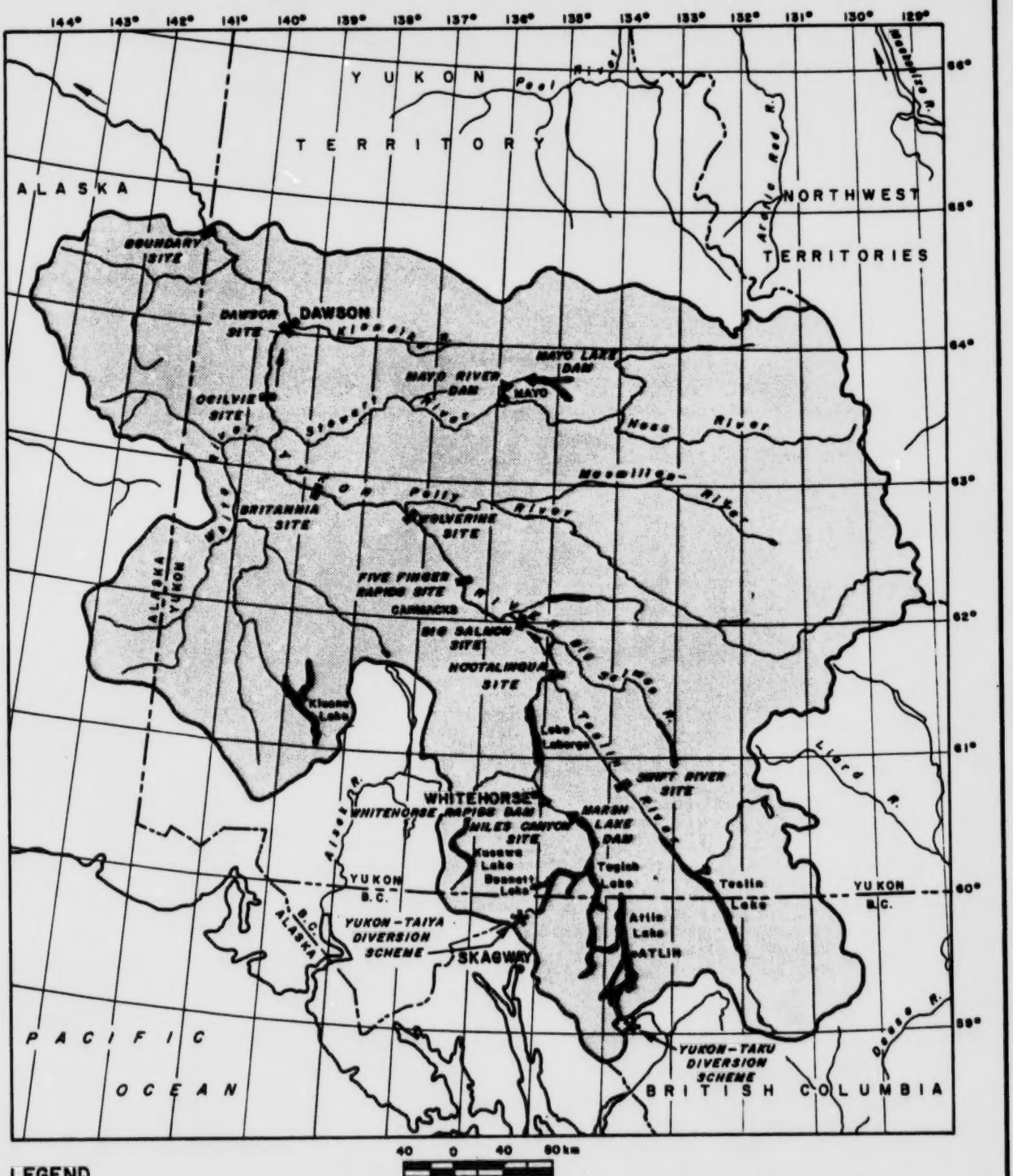
(2) A "Modified Plan" with main stem development only on the Lower Yukon, and utilizing residual flows after headwater diversion for the Yukon-Taiya or Yukon-Taku mega projects.

In this section of the report the "Major Plan" development only will be examined to determine the approximate reduction in power potential with reductions in permissible live storage. The full potential for the Yukon River main stem plants was given in the 1962 study as an installed capacity of 4,477,400 kW of which 3,387,400 kW was prime output or dependable power, with a primary capacity factor of 75%.[1]

---

[1] "Primary" Capacity Factor = $\frac{\text{Primary Output (Firm Power) in MW}}{\text{Installed Capacity in MW}} \times 100\%$

MONENCO CONSULTANTS PACIFIC LTD.



LEGEND

- DAMSITE INVESTIGATED 1956-1957
- EXISTING DAM
- DRAINAGE BASIN

REFERENCE: YUKON RIVER BASIN REPORT PLATE 25 DEPARTMENT OF NORTHERN AFFAIRS AND NATIONAL RESOURCES, WATER RESOURCES BRANCH, 1962

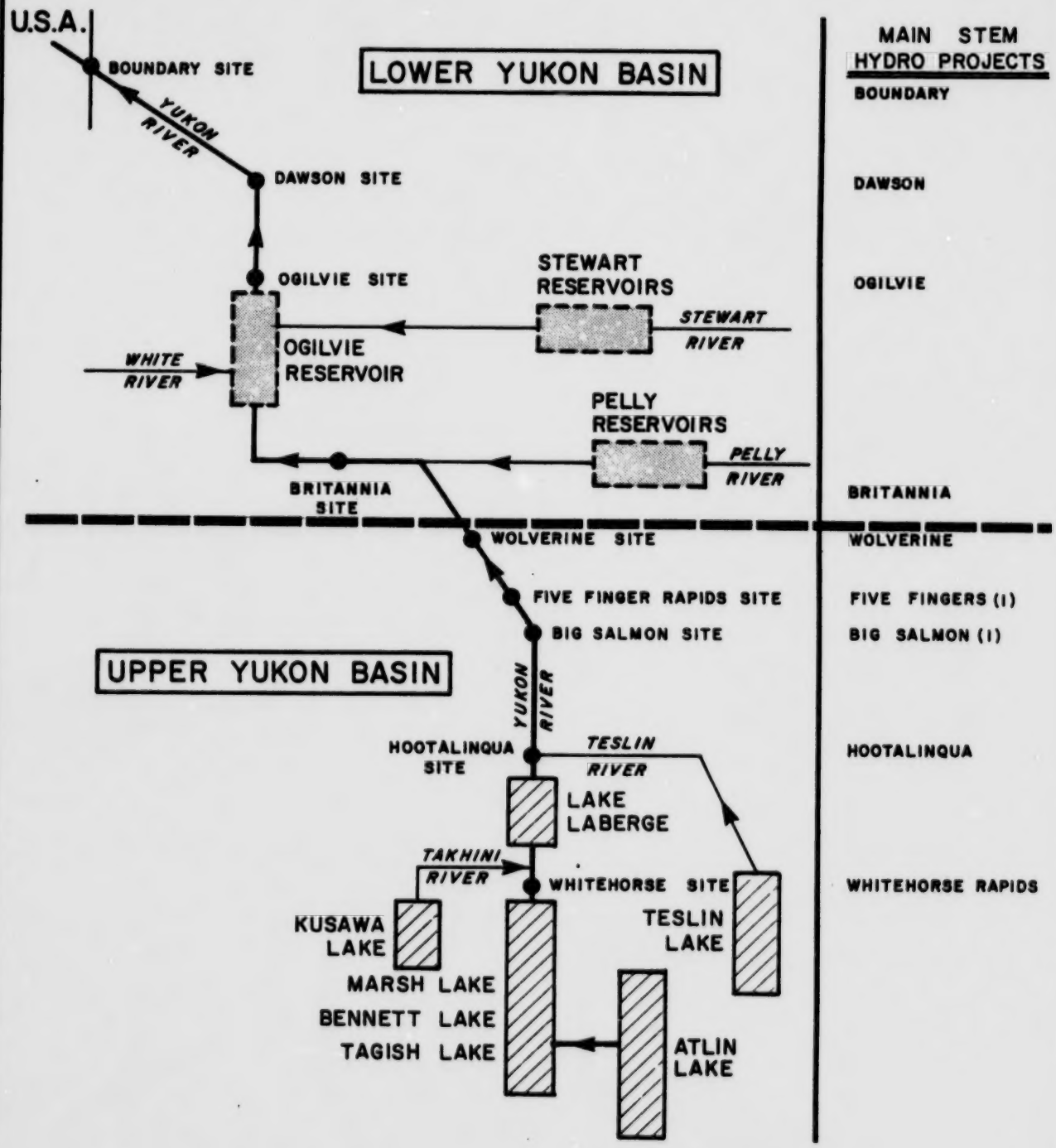
PLATE 6-1

NORTHERN CANADA POWER COMMISSION

YUKON HYDRO STORAGE STUDY

LOCATION OF POTENTIAL SITES ON THE YUKON RIVER

MONENCO CONSULTANTS PACIFIC LTD.



NOTES:
(1) THE MID-YUKON SITE IS AN ALTERNATE TO FIVE FINGERS AND BIG SALMON.

PLATE 6-2

NORTHERN CANADA POWER COMMISSION

YUKON HYDRO STORAGE STUDY

SCHEMATIC PLAN OF YUKON RIVER, LAKES AND RESERVOIRS

Reference should be made to Plate 6-2 which shows in schematic form the positions of the various reservoirs and lakes. The following factors are relevent in understanding the effect of storage changes.

(i) The Major Plan assumed development of all of the available head on the rivers under consideration. In other words, the forebay of each plant extended to the tailwater of the next plant upstream. In the Lower Yukon basin, the Pelly and Stewart Rivers were regulated by storage reservoirs on these rivers. The White River was regulated by a reservoir created by the Ogilvie project on the Yukon River just downstream from the Stewart/Yukon confluence.

(ii) Sufficient storage was designated at Teslin Lake, and at Marsh/Bennett/Tagish/Atlin Lakes to provide full regulation of the Teslin and Yukon Rivers. This required 41 ft. (12.5 m) of storage on Marsh/Tagish/Bennett between elevations 2,155 ft. and 2,196 ft, many times the historic range. On Teslin Lake, 25 ft. (7.6 m) of storage was designated between elevations 2,305 ft. and 2,330 ft., and on Atlin Lake, 2.3 m (7.5 ft.) of storage. In both cases approximately the historic range of levels.

(iii) No consideration was given to socio-environmental aspects. The implications of this relate to both the storage and head development along the rivers. With current realities, it is probable that development of the total head along the Yukon River and its main tributaries may be unrealistic, as is the concept of 41 ft. of reservoir storage on the Marsh/Bennett/Tagish Lakes chain.

6.3 Factors Reducing Hydro Potential

It is obvious that, with allowances for socio-environmental considerations, the power potential of the Yukon River will be reduced from the full potential envisaged by the 1962 Yukon River Basin Study. However, a reliable determination of the potential would require an extensive series of studies including possibly some different sites, and this is beyond the scope of this review. Socio-environmental factors would likely affect the locations and sizes of power plants, and the size and ranges of reservoirs. These effects would probably be manifested in the following ways:

(i) Smaller reservoirs, either in area or operating range, would result in lower dependable flows to the plants downstream since less regulation could be provided to control the variable river flows.

(ii) Lower dams to avoid, for example, flooding communities would result in less head or "drop" through the plants, thereby resulting in plants with smaller capacities.

(iii) The effects stated in the previous two points could have complex ramifications on the development scheme. With reduced power potentials, some sites might become economically unattractive and be dropped from development. In this regard, it seems most likely that any realistic development scheme would leave some of the available head undeveloped. Alternatively, some previously rejected sites might take on a renewed importance. In this regard, it is important to note that the 1962 Yukon River Basin Study evaluated in detail only those sites which fit

into the maximum development scenario assumed for the purposes of the study. It is recognized that many other potential sites exist on the Yukon River and its tributaries, and that some of these could become relatively more attractive under different socio-environmental constraints.

6.4 Storage Scenarios and Power Potentials

Although a determination of the realistic power potential of the Yukon River is beyond the scope of this study, it is possible to show the relative effects that various amounts of storage would have. This can be done by referring to the 1962 Yukon River Basin Study, which is the only study carried out to date of potential sites along the full length of the Yukon River in Yukon.

Since the purpose of storage in hydroelectric developments is to increase the firm or dependable flow, it is appropriate to compare various storage scenarios on the basis of the continuous energy which can be produced by them at the various plants along the river. Several such storage scenarios are shown in Table 6-2. Of these, three are most relevant for consideration of reduced Upper Yukon storage, and are compared in Table 6-3 (using the same column numbers). They are discussed herewith:

6.4.1 Potential With Full Regulation

Column 1, of Tables 6-2 and 6-3, shows the firm or prime output of the various Yukon River sites as determined by the 1962 Yukon River Basin Study under conditions of full headwater regulation on the Teslin and Yukon Rivers; that is, with 7.6 m of storage on Teslin Lake, 12.5 m on Marsh/ Bennett/Tagish Lakes and 2.3 m on Atlin Lake.

It is important to note that under this scenario, substantial storage is also provided at the Yukon River Ogilvie site for regulation of inflows from the White River, and that regulation is also provided on the Pelly and Stewart Rivers.

With full regulation, the total primary capacity of the Yukon River was given as 3389 MW.

6.4.2 Reduced Potential With No Upper Yukon Regulation, But Lower Yukon Storage as in 1962 Study

This scenario has no headwater storage on the Yukon or Teslin Rivers, other than natural lake storage, but has Lower Yukon storage for the Pelly, Stewart and White Rivers, the latter at the Ogilvie reservoir.

For the Teslin River, the unregulated flow was simply taken as the minimum recorded flow at Johnson's Crossing, located at the outlet of Teslin Lake. This was found to be 38.2 m^3/s. In the case of the Yukon River, some form of regulation has been in effect for most of the period of hydrometric record - originally for navigation purposes, and

more recently for hydroelectric power generation. However by inspection of the record including a period between 1962 and 1969 when the river was essentially unregulated, a minimum recorded flow of 32.6 m^3/s was assumed.

Column 2 shows the power potential under the scenario described above. The total potential is some 2029 MW, which is 60% of the full potential shown in Column 1. Column 1 and 2, therefore, represent the two extreme storage scenarios; namely, full regulation and no regulation on the Upper Yukon.

6.4.3 Potential with Full Lower Yukon Storage but with Upper Yukon Storage within "Historic" Limits on Teslin and Marsh/Bennett/Tagish Lakes and Atlin Lake

Having considered the two extreme Upper Yukon storage scenarios, that is with full regulation (Column 1), and with no man-made regulation (Column 2) it was desired to evaluate an intermediate situation. Specifically, it was decided to determine what the Yukon River power potential would be if headwater storage was developed within a range approximating to the natural, historically recorded ranges of Teslin, Marsh, Bennett, Tagish, and Atlin Lakes. Lower Yukon storage remains as in the previous two scenarios.

It is considered that controlled storage within historic lake limits is a scenario which is generally reasonable, and realistic in terms of its socio-environmental impact. Particularly in view of the fact that a large proportion of the full potential could be realised even under such restrictions.

The amounts of storage which are attainable within the historic ranges of the various lakes are shown in Table 6-4. In the case of Marsh/Bennett/Tagish Lake, the conservative assumption of storage up to the licenced limit of elevation 2,153 feet (656.23 m) was assumed. This is over two feet lower than the historic high level, and reflects not only the licence limits, but also restrictions at low lake levels at Marsh Lake and Tagish Lake outlet channels. In the case of Atlin Lake, equivalent regulation of only 1.5 m, slightly less than the historic range, was used as a conservative assumption of the type of flow control projected. In the case of Teslin Lake, the 1962 Yukon River Basin Study specified storage only within historic limits; however, the storage control structure was located some 30 km downstream of Teslin Lake with storage area increased by flooding this river valley. Moving the control to the outlet of the lake is more conservative, and would reduce the volume of storage to that shown in Table 6-4.

The storage used in this scenario, hereafter designated as "historic" range, is accordingly slightly less than that available with the full historic range on all lakes. Storage assumed on the Marsh/Tagish/Bennett Lakes system reflects current or projected use with only the 40 MW Whitehorse Rapids plant on the Yukon main stem. Greater storage on these lakes would be justified with further Yukon main stem development, but some reduction of the full Teslin Lake range may be found appropriate on further study.

Column 3 shows the Yukon River potential with this "historic range" Upper Yukon storage. The dependable regulated flows used to calculate this potential were taken from Table 2-1 (p. 2-4) of the 1980 Mid Yukon Study - Engineering Report. The total potential is 2680 MW continuous, which is 79% of the full potencial by the 1962 Yukon Basin Study.

6.5 Yukon River Development with Reduced Storage

A comparison of the power potential for these three storage scenarios broken down into Upper and Lower Yukon basin potentials can best be made by considering Table 6-3.

It will be noted that the relationship between power potential and decreasing Upper Yukon storage

	from: full	-> "historic" range	-> nil
for the entire Yukon Basin is ->	100 :	79 :	60
while for the Upper Basin Plants alone the ratios are ->	100 :	66 :	34
and for the Lower Basin Plants alone ->	100 :	86 :	73

This helps to explain why the reduction of Yukon River power potential resulting from decrease in the principal storage (Marsh/Tagish/Bennett Lakes) from 12.5 m to 1.9 m is only 21%. The Lower Yukon plants which comprise some 67% of the total Yukon River potential have the benefit of the Lower Yukon storage for the Pelly, Stewart and White Rivers and so are only modestly affected by the loss of Upper Yukon storage. The reduction of the Upper Yukon power potential is much more marked but still provides 66% of the full storage potential where "historic" range storage can be utilized.

It is apparent that the unexpectedly small reductions in power potential with reduced head water storage, reflect, in addition to unchanged Lower Yukon storage, the natural regulation provided by the headwater lake storage. Furthermore, as shown on Plate 3-2, the "diminishing returns" of dependable flow with increasing storage can be seen since the loss of the upper half of the full 12.5 m (40 ft) storage

range on Marsh/Tagish/Bennett Lakes reduces dependable flow by only 12%. This loss is primarily in the regulation of cyclical flow variation which is required only infrequently.

The case where the Pelly and Stewart storage is not developed is covered in Cols 5, 6 and 7 in Table 6-2. Some 64% of the full power potential is still available on the main stem Yukon plants, provided Upper Yukon storage to "historic" limits is available. With no storage in either Upper or Lower Yukon Basin (excluding the Ogilvie reservoir) only 38% of the full potential would be available.

It is prudent to draw attention again to the further reduction in power potential which may be necessary due to modified projects, reduced head, and compensation flows required to mitigate socio-environmental effects. The importance of assessing this is clear, if the realistic potential of the Yukon River is to be known. Offsetting this reduction, will be any permissible increase in storage above the "historic" range of the head water lakes, or in the use of other lakes such as Laberge and Kusawa for storage. Referring to Column 4 in Table 6-2 it will be noted that storage from these latter lakes within "historic" range would provide an increase in dependable flow to the main stem of about 4% and raise the "historic" range potential from 79% to 83% of the Column 1 figure. Furthermore, if the full theoretical historic range on Atlin and Marsh/Tagish/Bennett Lake could be used, a further increase of about 2% would be possible.

6.6 Yukon-Taiya and Yukon-Taku Potentials with Reduced Storage

Clearly with the surprising high dependable flows obtainable with reduced storage, the Yukon-Taiya and

Yukon-Taku schemes should be re-examined for power potential. These projects essentially use the Upper Yukon basin flows and storage with full development, so that about 2/3 of the firm flow should be available for these diversion schemes. However there are more complex considerations including other environmental impacts, and the need for additional pumping plants. These will further reduce the available power, but by how much cannot be determined without additional study outside the scope of this report.

6.7 Relative Importance of Upper Yukon Lakes for Storage

Table 6-4 lists the principal lakes with their areas, historic storage ranges and live storage volumes. It will be noted that the Marsh/Tagish/Bennett Lakes chain and Atlin Lake have the greatest areas (almost equal), and comparable historic ranges with associated storage volumes.

However Teslin Lake, with an area only two thirds as great, has a historic range much greater than that of the other major lakes and so an associated live storage comparable with Marsh, Bennett, Tagish and Atlin Lakes together. Laberge and Kusawa Lakes are of lesser importance but can provide significant storage.

TABLE 6-2

Yukon Main Stem Firm Capacities for Various Storage Scenarios

Capacities in MW

Site	Scenario: With Regulation of Pelly and Stewart Rivers 1	2	3	4	Without Regulation of Pelly and Stewart Rivers 5	6	7
Whitehorse	35	4	26	26	35	4	26
Hootalinqua	185	49	112	126	185	49	112
Big Salmon	216	66	134	148	216	66	134
Five Fingers	336	124	224	246	336	124	224
Wolverine	360	145	250	272	360	145	250
Upper Yukon Total	1132 (100%)	388 (34%)	746 (66%)	818 (72%)	1132	388	746
Britannia	391	217	298	315	290	120	262
Ogilvie	637	475	552	568	402	241	376
Dawson	500	373	431	443	319	198	299
Boundary	729	576	653	670	501	338	475
YUKON R. TOTAL	3389 100%	2029 60%	2680 79%	2814 83%	2644	1285	2158

Scenarios:
1. Per 1962 Yukon River Basin Study (YRBS).
2. Per YRBS, except no head water storage on Yukon or Teslin.
3. Per YRBS, except storage to "historic" range on Marsh, Tagish, Bennett, Teslin, and Atlin.
4. Same as 3, but with storage within historic range on Kusawa Lake and Lake Laberge.
5. Per YRBS, except no regulation of Pelly and Stewart Rivers.
6. Per YRBS, except no head water storage on Yukon or Teslin, and no regulation of Pelly or Stewart.
7. Same as 3, but no regulation of Pelly or Stewart.

NOTE: Capacities tabulated are approximate with accuracy less than might be inferred by significant figures provided.

TABLE 6-3

Limitation of Prime Power Potential
by Reduced Upper Yukon Storage

Project	Col. 1 Prime Generating Capacity Supported by Full Regulation MW	Col. 1 (%)	Col. 2 Prime Generating Capacity Supported by No Regulation MW	Col. 2 (%)	Col. 3 Prime Generating Capacity Supported by Continuous Flow in MW "Historic" Range (2) MW	Col. 3 (%)
Upper Yukon Basin						
Whitehorse	35	(100)	4	(12)	26	(74)
Hootalinqua	185	(100)	49	(26)	112	(61)
Big Salmon	216	(100)	66	(31)	134	(62)
Five Fingers	336	(100)	124	(37)	224	(67)
Wolverine	360	(100)	145	(40)	250	(69)
Sub-total	1132	(100)	388	(34)	746	(66)
Lower Yukon Basin						
Britannia	391	(100)	217	(55)	298	(76)
Ogilvie	637	(100)	475	(75)	552	(87)
Dawson	500	(100)	373	(75)	431	(86)
Boundary	729	(100)	576	(79)	653	(90)
Sub-total	2257	(100)	1641	(73)	1934	(86)
YUKON R. TOTAL	3389	(100)	2029	(60)	2680	(79)
Yukon R. Total Installed Capacity @ 60% Capacity Factor	5650 MW		3380 MW		4470 MW	
Yukon R. Total Installed Capacity @ 75% Capacity Factor	4520 MW		2710 MW		3570 MW	

Note: (1) Full Lower Yukon storage as in 1962 Yukon River Basin Study is assumed.

(2) "Historic" Range on Marsh, Tagish, Bennett, Teslin, and Atlin Lakes. Dependable flows are taken from the Mid Yukon Study - Engineering Report by Monenco Consultants Pacific Ltd. - 1980 and are approximate only.

TABLE 6-4

Upper Yukon River Lake Storages

Lake	Area (km^2)	Storage Within Historic Range Range (m)	Volume ($m^3 \times 10^6$)
Marsh)			
Bennett)	550	1.9(3)	1050
Tagish)		2.8	1540
Atlin	580	1.5(4)	880
		2.3	1330
Teslin	380	6.8	2580
Laberge	200	2.7	550
Kusawa	140	2.6	360

Notes: (1) Control dams are located at lake outlets.

(2) Storage within historic range is theoretical maximum, not fully attainable in some cases due to outflow constraints at minimum lake levels.

(3) Existing (licenced) range.

(4) As assumed for a recently studied Atlin storage scheme.

7. SUMMARY AND CONCLUSIONS

This study draws attention to the following aspects of storage, with particular reference to its importance to the Yukon hydroelectric potential.

1) Storage of many basic commodities including water has been crucial to mankind's survival from prehistory, and is still essential to the quality of life. Storage is also essential to some wildlife.

2) Water storage dams can often be multi-purpose developments and benefits can include some of the following:

- flood control
- water supply - domestic and industrial
- pollution alleviation
- water based recreation including sport fishing
- fisheries enhancement - water for hatcheries, etc.
- tourist attraction

The Whitehorse Rapids hydro plant has several of these non-power benefits. Such benefits are less publicized than any negative impacts.

3) Flow control from storage is necessary for hydroelectric development, particularly in the North, in order to reduce seasonal and cyclical river flow variations, which may have a maximum/minimum ratio as high as 300/1. At the same time the electric power demand to be met is normally highest at mid-winter, when unregulated

river flows are low. The majority of hydro schemes in the North would not be practical or economic without storage.

4) Alternatives to storage or methods to reduce storage requirements are:

- Thermal generation to replace hydro in low flow periods.

- Interconnection with another power system with surplus storage or standby capacity.

- Rationing power during low flow periods.

- Construction of hydro on naturally well regulated rivers.

These do not appear to offer practical long term solutions in the near future.

5) In summary, the hydroelectric storage reservoir is the means by which a seasonally varying and cyclically uncertain water supply can be made to provide a reliable and continuous power supply to meet a varying demand.

6) Comparison of the alternative methods of obtaining storage: artificial reservoirs vs augmented natural lake storages, suggests that in most cases the latter will be found the better choice for both lower costs and lesser socio-environmental effects. Chief factors in favour of lake storage are:

- minimum land area flooded
- lower storage dam or control structure
- less fish migration and navigation problems
- minimum clearing costs
- less reservoir drawdown

7) There is a need for reservoir clearing standards to be studied and for guidance to be available prior to application for water licence. With clearing costs up to 25% of project capital costs, the proper choice of project requires clearing cost to be estimated as accurately as possible. Costly delays may result if this is not known and wrong project selection is made.

8) Socio-environmental effects should be minimized as far as possible during project conceptual design, with any additional mitigation and enhancement measures found practical also incorporated.

Main problems to be overcome are:

- effects of reservoir flooding and water level changes
- restriction to fish migration and navigation by dams
- downstream flow changes

9) Resolution of the development/environment conflict in an orderly and expeditious manner is a priority. The adversary system in use has significant weaknesses. The multi-disciplinary team approach is suggested as a promising way to achieve the best choice for society, with maximum benefits and minimum costs, both financial and socio-environmental.

A multiple use study, separate from the environmental impact study, is suggested to examine the questions of non power benefits, and possible mitigation and enhancement measures. Follow-up studies on socio-environmental impacts observed on operating projects are most necessary to allow comparison with intervenor's predictions and provide guidance for future development.

10) Flow regulation by storage is most crucial for the smaller rivers without headwater lakes to provide natural regulation. For example three potential projects under investigation in the 30 MW to 60 MW range would have a practical plant size of only 5% to 10% of design capacity without any storage, and would not be economic. This would apply in some degree to a majority of such plants in the Yukon.

11) The potential of the Yukon River main stem is less dependent on storage, but could provide a significant percentage, almost 80% of its full potential, if the headwater lakes of Marsh, Tagish, Bennett, Teslin and Atlin can be controlled within their historic range. Without even this storage the potential would drop to 60% of the full potential and if there was no storage on the Pelly and Stewart tributaries there would be a further drop to less than 40%.

12) The 1962 Yukon River Basin study put forward a "Major Plan" of Yukon Basin development with a main stem power potential of 3400 MW continuous generation considering full storage on the Upper and Lower Yukon Basins.

However, the study did not take into account socio-environmental factors and utilized 12.5 metres of storage on Marsh Lake, so that it is not now seen as an acceptable scheme without modification.

13) Using the 1962 study flow data and that from the Mid Yukon Study of 1980, the effect of reducing storage on the power potential of the main stem plants was examined and revealed that the following installed capacities (75% Capacity Factor) would be theoretically possible.

	Full Regulation 1962 Study Scenario	No Upper Yukon Headwater Regulation	"Historic" Range Upper Yukon Storage Regulation
Lower Yukon River	3010 (100%)	2190 (73%)	2570 (86%)
Upper Yukon River	1510 (100%)	520 (34%)	1000 (66%)
Total Yukon River	4520 (100%)	2710 (60%)	3570 (79%)

The high proportion of full potential available with the modest "historic" range storage reflects the large increase in dependable flow obtained with the first added storage increments, and also the influence of the Lower Yukon storage retained in these scenarios.

14) Other reductions in power potential will probably be necessary to meet socio-environmental concerns not related to storage. There are however some offsetting possibilities, including storage increased above the historic range, and the use of Kusawa and Laberge Lakes. Using these lakes for storage to historic limits would raise the Yukon River potential by a further 4% to about 3750 MW installed capacity (75% CF)

15) Protection of the option of regulating the headwater lakes of the Yukon River within historic levels is most important. Teslin Lake is seen as the most important, with a much greater historic range storage than any other lake.

16) The Yukon-Taku and Yukon-Taiya diversion schemes will lose more power potential than main stem plants by reduced storage, but considering their magnitude and relatively low indicated energy costs, further studies on this matter are merited.

8. RECOMMENDATIONS

The recommendations arising from the study are discussed in the previous sections of the report and are assembled here in summary form.

(1) It is recommended that the desirability of multiple use resource development should be re-emphasized, with the non power benefits of storage projects defined and described.

(2) Critical examination is required of the existing adversary treatment of socio-environmental vs storage development conflicts. Multi-disciplinary cooperation is seen as a more promising route.

(3) Protection of the option to develop Basin lakes at least within the historic range of levels is recommended. In the Upper Yukon Basin, Teslin Lake is particularly important.

(4) Reservoir clearing standards should be studied by the regulatory authorities so that guidance will be available on request by storage development designers to assist in proper project selection.

(5) A multiple use study of non-power benefits, and mitigation and enhancement measures is recommended for future projects, in addition to the usual socio-environmental impact study.

(6) Socio-environmental follow up studies on completed projects are recommended to minimize reliance on unsubstantiated predictions of impacts in future development studies.

(7) Further study of the realistic Yukon main stem power potential is required taking into account other factors than that of reduced storage.

(8) Similar studies are suggested for the Yukon-Taiya and Yukon-Taku projects.

A further recommendation arises from concerns addressed in (2) above, but which were not central to the scope of this study. It derives in major part from power utility experience and frustration with the existing adversary system of conflict resolution.

(9) It is recommended that a study be made of the existing methods of resolving conflicts arising from water storage development schemes, with emphasis on the performance record of these existing methods in providing rapid and satisfactory resolution in the best interests of society. This latter criteria is seen to encompass multiple use of the resource, minimising water user conflicts and making full use of practical mitigation and enhancement measures. The study should call on experience not only in North America but also from overseas.

APPENDIX A

WATER STORAGE RESERVOIRS

A Conservation of Natural Resources

Jack K. Sexton, P. ENG.
Montreal Engineering Company, Limited
Vancouver, B.C.

Introductory

In recent years the world has suddenly become aware of the pressures of population growth on the one hand, and the limitations of the material resources of our planet to support such growth, on the other. Added to these concerns, particularly on the relatively affluent North American continent, is an awareness of the need to preserve the amenities of our environment in both the harvesting and utilization of our resources. These issues are emotionally charged; and their impact on the adversary system, whereby we reach decisions in our democratic society, has resulted in some exaggeration and irrationality. Small groups have risen up in opposition to almost every plan put forward for utilization of our resources; and frequently they have assumed unto themselves all the virtues of crusaders for righteousness (as emotionally opinionated groups have done throughout history). In so doing they have succeeded in bringing into questionable repute many of the facets of natural resource development – whether they concern energy, forestry, mining, or just the everyday business of developing a plot of land on which to live; all of which brings us to the subject of this paper, because some of the most maligned developments are the dams and reservoirs required in the conservation and utilization of water resources. Lest such adverse propaganda raise doubts in the minds of young engineers starting out in the professional world, it is proposed in this discussion to examine briefly the constructive role which conservation of water resources has played in human development to date – and must continue to play in the future.

Natural river flows

The natural flows of water in the rivers, streams and water courses of the world fluctuate with the movement of the earth around the sun. The basic variation is the annual cycle of increase and decrease with the changing seasons of the year; and superimposed thereon are longer term fluctuations in both total annual volume of flow and its seasonal distribution. The streamflows of Canadian Rivers are typical of the high latitudes of the Northern Hemisphere. In all but a few cases on the east and west coasts they have a basic annual rhythm of rise and fall, somewhat as follows:

A peak flood flow – usually in late spring.

A somewhat irregular decline in flow over the following frost-free months – varying with local precipitation and temperatures.

A continuing decline of a more uniform character with the onset of freezing winter weather as streamflows, become almost entirely dependent on stored water - until the annual minimum flow is reached in late winter or early spring.

Then the start of an upward trend, gradual at first as the warming temperatures of spring take effect, then more rapid as snows melt and rains fall until the peak flood arrives to start the cycle over again.

The pattern changes with the maritime conditions on both the east and west coasts. In the Maritime Provinces of Eastern Canada there are usually two flood seasons of the year, one in the fall due to the heavy rains which precede the onset of winter, and the other in the late spring - as in the rest of the country. On the west coast the rivers draining the Pacific slopes of the Coast Mountains, such as the Cheakamus, Squamish and Homathko, tend toward an annual pattern of streamflow somewhat the reverse of that of the interior rivers, the high flows occurring in winter and the lows in summer. It is to be noted, however, that the principal west coast river, the Fraser, derives most of its water from the interior plateau, and hence has an annual pattern of streamflow like the rivers of the continental interior.

In warmer climates, where the land is not subject to an annual freeze-up, and particularly in subtropical and tropical regions, other annual patterns of streamflow prevail. However, regardless of location in the world, the net result of such patterns is usually the same - a disproportionately large part of the total annual volume

of streamflow discharging out to sea in a relatively short period of time each year. In extreme cases, such as in the water courses of semiarid areas of the Middle East and North Africa, almost the entire annual flow of water may be discharged in a matter of days.

In Canada some streamflow occurs in the rivers all year round, except for a few streams in the far north where the flow may literally freeze up completely in wintertime. The range of annual fluctuation, however, is usually large. In our own Province of British Columbia, for example, the recorded maximum natural flow of the Columbia is some 50 times its recorded minimum; and the ratio for other rivers becomes progressively greater with distance to the north, the recorded maximum flow of the Skeena being about 120 times its minimum. As a general rule, about 80% of the total annual volume of streamflow of the rivers in this Province is discharged during the six warm weather months from May through October.

Natural regulation of streamflow

The major factor in nature tending to reduce the seasonal range of streamflows is the storage capacity in a river basin which holds back part of the flood runoff and releases it later in the year to augment low flows. Such storage may be provided on the surface by lakes and swamps, or underground in a pervious soil. Our glaciated terrain in Canada has left us with an exceptional legacy of natural surface storage. The outstanding example, of course, is that of the Great Lakes, which regulate the natural flow of the St.Lawrence River to a remarkable degree, the recorded maximum flow being 2.21 times the recorded minimum, and the average annual ratio of maximum to minimum flows being about 1.4. The lakes in Manitoba also provide great natural regulation for the Nelson River; as does Reindeer Lake for the Churchill River and the Lake of the Woods for the Winnipeg River. Closer to home, the Tagish, Atlin and Teslin Lakes on the northern border of British Columbia provide a measure of natural regulation for the upper reaches of the Yukon River. The resulting average ratios of maximum to minimum flows for these rivers are summarized in the following table:

RIVER	AT	Ratio of Recorded Maximum to Recorded Minimum Flows	Average Annual Ratio of Maximum to Minimum Flows
St.Lawrence	Cornwall	2.2	1.4
Churchill	Granville Falls	3.1	1.7
Nelson	Below Sipiswesk	6.7	1.9
Winnipeg	Slave Falls	10.7	2.6
Yukon	Whitehorse	25.0	9.0

In Europe and Asia, on the other hand, there is much less natural surface storage. Apparently, the glaciers of Eurasia in the Pleistocene Epoch did not travel and scour as much as they did in North America. Next to Canada, probably the most extensive natural surface storage occurs in Africa, where the Great Rift has left a chain of lakes extending from Lake Rudolph in the north to Lake Nyassa in the south.

On the other hand, Canada is relatively poor in underground storage for its rivers, partly because the same Pleistocene glaciers that gouged out our great natural surface storages also scraped much of the soil from our land and moved it south to the mid-continental prairies - mostly in the United States. Moreover, a subarctic climate prevails over much of Canada, leaving our northern soils permanently frozen to great depths; and even in the south of Canada much of our land surface may be frozen when the spring runoffs occur. In other prats of the world, however, underground storage may play a significant role in reducing seasonal variation in streamflows. For example, the gentle slopes and porous soils of the vast savannas of Southeastern Brazil provide an abundance of natural underground storage that serves to maintain dry season streamflows at a relatively high level. As a result, in that part of Brazil it is possible to obtain full practical regulation of a river by creating an aggregate utilizable volume of surface storage equal to about one quarter of its total annual volume of streamflow. In Canada, unless a river happens to be one

of those with great natural storage, it normally requires the creation of reservoirs with a usable volume equal to more than half the total annual volume of flow to obtain a comparable result. In British Columbia, for example, some 60% of the total annual volume of flow is required.

The history of man-made surface reservoirs (1)

Since fresh water is the dominant element in our lives, man has had to contend with the irregularities of natural streamflow as our civilization has evolved. Early civilizations tended to rise in benign climates along the banks of such dependable rivers as the Tigris, Euphrates, the Nile, and the Indus. In adjacent regions of less dependable water supply man was limited to a nomadic existence until he learned to conserve natural streamflows. Such conservation of water in artificial surface reservoirs must indeed have been a milestone in his progress - probably comparable to the domestication of wild animals. In fact, the regulation of natural streamflows for man's use can be regarded as a form of domestication. The first storage reservoirs were probably created on seasonal water courses which were dry part of the year, and on which simple retention structures could easily be built. The earliest such dam of which there is evidence was built some 4500 years ago at Sadd el-Kafara on a seasonal water course some 20 miles south of Cairo, probably to provide water for workmen in a nearby alabaster quarry. Elsewhere in the Middle East such reservoirs enabled relatively large agricultural populations to live in regions which now support a few nomads. Probably the best known example of such construction is the Marib Dam on a seasonal water course in Yemen near the southwest corner of the Arabian Peninsula, fascinating relics of which still remain. The original structure was built about 750 B.C. and was modified over the centuries which followed. It attained its final form early in the fourth century A.D., and was eventually abandoned in 575 A.D.

In 146 B.C. the Romans destroyed Carthage and subsequently spread their control to the east of the Mediterranean where they encountered the ancient civilizations practicing water conservation, as at Marib. They were quick to appreciate the benefits of such practices; and subsequently used them to create a rich agricultural empire around the Mediterranean - particularly in North Africa where desert conditions now prevail. Remnants of a number of the dams built by the Romans in those times to store water can still be seen. They also built storage dams in Europe, a few in Italy, some in southern France, but the greatest number in Spain, where Roman civilization probably ran its longest course in Western Europe.

With the fall of the empire based on Rome in the fourth and fifth centuries A.D. and the onset of the Dark Ages the building of storage dams came to an end in western civilization, and was not revived for almost 900 years. The first significant revival occurred in Spain, where the most extensive water conservation developments in Europe had originally taken place. The Visigoths had brought development in that country to a halt with their arrival in the fifth century A.D., and did little more than maintain the status quo until they in turn were overrun by the Moslems three centuries later. Under the Moslems the south of Spain was revitalized, and a period of prosperity ensued in which many dams were built. Strangely, however, these dams, almost without exception were built for the diversion of existing waters for irrigation and consumptive uses. Only in one case, that of the Almonacid Dam on the Ebro River, is there any evidence that the original structure may have been built by the Moslems to store water- and it is by no means certain. Not until the resurgence of the Christians is the evidence clear that dams were once more built in Spain to store water, the first of the new developments being built in the thirteenth century before the Christian reconquest was complete. And such was the vigour of the new Christian Spain that two and a half centuries later they were to lead the way into the New World and bring their water conservations practices with them. In the mid-1570's they built the Chalviri Dam near Potosi in what is now Bolivia to provide water for more than 100 mills crushing the silver ores of the fabulous Cerro Rico, and thus became the first Europeans to develop a storage reservoir in the Americas.

Meanwhile, with the coming of the Renaissance the idea of building dams for the storage of water took hold in the rest of Europe. Even Leonardo da Vinci participated in the action with a scheme to construct a number of flood control dams in the Arezzo basin of the Arno to protect Florence. Nothing came of his scheme; and probably the first significant post Roman storage dam in Continental Europe outside of Spain was the Spiegelfreudersee, which was built near Tarrenz in Austria in 1460 for an unusual purpose–to enhance fish supplies in an age when religious restrictions on diet may have been more rigorously observed in Europe than they are now.

The next impetus in the building of dams for storage reservoirs in Europe came with the Industrial Revolution in the eighteenth century - primarily for navigation and water power. France probably led the way in the former by creating the first large reservoirs outside of Spain to facilitate navigation across summits between river basins. Britain was also active in the creation of reservoirs for inland navigation, but in their case the reservoirs were normally used to sustain streamflows during periods of drought, rather than facilitate passage over summits. In this connection it is interesting to note one small storage reservoir in England that preceded even those of Christian Spain. In the latter part of the twelfth century the Bishop of Winchester built an earth dam at Alresford to create a storage reservoir with an area of about 200 acres to supply navigation water for a series of simple locks on the River Itchen. That reservoir, although now much reduced in size by sediments, is still in use for irrigation of water cress beds downstream.

With the coming of the nineteenth century the creation of reservoirs to regulate and control streamflows was accelerated in the industrialized countries of Europe and spread overseas to America. Probably the first storage dam of significance in the United States was built on the Schuylkill River at Fairmont near Philadelphia in 1819. Better known among early American storage dams is the one built on the Croton River between 1837 and 1842 to supply water to the City of New York. The first storage dam in Canada was built at Jones Falls on the Cataraqui River in Ontario in 1832 as part of the Rideau Canal system. (2)

The building of dams for storage reservoirs also spread to the Far East, particularly to India where the British began developing irrigation. One of the earliest storage dams they built was on the Coleroon outlet of the Cauvery in the State of Madras in 1836. Located on a soft alluvial foundation the dam was subject to recurring difficulties until completely rebuilt toward the end of the century. These troubles, however, served to highlight the fact that the Coleroon dam replaced an earlier dam on the Cauvery that had been built under similar difficulties in the second century A.D. and had continued in operation until the early nineteenth before becoming silted up.

The foregoing summary has been limited to the history of storage dams in western civilization. The second century dam on the Cauvery, however, is a reminder that the record of ancient storage developments in the Far East is also impressive.

Modern storage reservoirs

The present century has brought the greatest advances of all time in the creation of storage reservoirs to further control the erratic streamflows of nature (and domesticate them, as it were) for human use. As populations have expanded, the need for assured water supplies for consumptive uses has grown, and with it the need for similar supplies for irrigation to produce more food, and for power to supply energy needs. Likewise, there has been a growing need to hold back destructive floods from riparian areas, and to control water levels for navigation - and finally in some areas to create artificial lakes for recreational purposes. These varied objectives of streamflow control have been brought together in the modern multipurpose project. Such projects have become particularly appropriate in countries such as the United States of America with large irrigation potential in semiarid areas. Here in Canada our climate does not normally give rise to the need for storage projects with a wide range of multipurpose uses. Our reservoirs are nonetheless essential to our progress. We have a few of them to provide irrigation water, such as the Saint Mary's in southwestern Alberta and the lesser reservoirs supplying irrigation water to the Okanagan Valley. We also have a few flood control reservoirs such as at Fanshaw on the North Thames River in Ontario. In at least two cases (i.e. at Brazeau and Big Horn in the Province of Alberta) we have reservoirs that were created in part to increase winterflows and thereby alleviate pollution conditions downstream. As for navigation, we have the various impoundments created years ago for the canal systems in Ontario, and more recently those on the St-Lawrence River for the Seaway and for power, although these may not be classified as reservoirs. One reservoir that definitely was created for navigation, however, is at Marsh Lake on the Yukon River. It was created to provide water for flushing the ice out of the river downstream to allow an earlier start of steamboat navigation from Whitehorse to Dawson each year. We also have at least one great reservoir (i.e. Lake Diefenbaker on the South Saskatchewan River) which can be considered has having been built partially for recreational values. However, the great majority of storage reservoirs in Canada have been created to regulate streamflows for

hydroelectric power and for municipal consumptive uses, the former being one of the bases of our national economy. All the provinces and territories except Prince Edward Island, are dependent on water, regulated by reservoirs, for at least part of their power supply; and some, such as British Columbia, Manitoba, Quebec and Newfoundland, are almost entirely dependent on it.

The adverse effects of storage reservoirs

Having thus described the benefits that man has derived from the control of natural waters by reservoirs down through history, it must now be pointed out that reservoirs can also have adverse consequences, at least temporarily; and the more crowded the world becomes, the more significant these negative consequences may also become. The basic disadvantage arises from the fact that a reservoir involves the flooding of land and its withdrawal from public use, either direct or indirect. This may involve the destruction of agricultural land in a world already beginning to worry about the adequacy of its food supplies. It may also involve large scale displacement of peoples, which can be excessively difficult in a densely populated country. For example, hydro investigations sponsored by the Canadian Government in China at the end of the Second World War encountered cases where the creation of a relatively small reservoir would displace tens of thousands of people, who could be relocated only with enormous difficulty. However, in a thinly populated country such as Canada the flooding of land normally creates few fundamental problems, although undoubtedly there are inconveniences which arise at least temporarily. Arable land has been relatively plentiful, and the submergence of a few square miles has had no severe impact on the economy. People displaced from one area can usually locate themselves elsewhere without excessive difficulty or hardship. Here in British Columbia, however, a special case of potential agricultural loss from reservoir creation was encountered in the investigation of the proposed Moran reservoir in the Provincial Power Study in 1972. In that case the small areas of arable valley bottom land near the upstream end of the reservoir site support a negligible human population, but they are vital to local ranches, the main industry of the district, because of the feed crops they produce to complement the grazing ranges higher up the flanks of the valley.

Interference with the migrations of anadromous fish may also be a serious consequence of reservoir construction, particularly if the dams involved are more than about 100 feet in height. This is the situation on the west and east coasts of Canada where the salmon fishing industries are of primary importance. In some cases the adverse effects of the storage dams on the fish runs can be overcome by the introduction of fish hatcheries. An excellent example of such corrective measures being the fish hatchery now in successful operation on the Capilano River below the Cleveland Dam. On the east coast the hatchery constructed downstream of the Mactaquac Dam on the Saint John River is a somewhat similar example. Fish ladders can also be used to facilitate the upstream passage of the fish, and special precautions can be taken in the design of the discharge works to facilitate the downstream movement of the fingerlings. The downstream passage, however, is usually the limiting factor. If the impounding dam is more than 100 feet high it becomes all but impossible to guarantee the safe return of the young fish. This was the situation encountered in the study of the Moran Dam on the Fraser. The dam would be about 800 feet high; and with present technology there is no practical way of getting the young fish downstream. Hence, it must be assumed that if the dam were constructed, that part of the Fraser River salmon run travelling upstream of Moran would be lost. This fact was one of the primary reasons for the recommendation against construction of the Moran Dam given in the report on the Provincial Power Study.

In British Columbia a problem with indigenous populations may also be encountered in the creation of reservoirs. For example, on the banks of the Fraser River between Lillooet and Quesnel there are 27 Indian Reservations that would be flooded at least in part if major development of the main stem of the river were undertaken. These reservations support scant local populations, but they are used in season by the Indian peoples to gather a harvest of salmon. Such fishing so far upstream in the migration route is probably a marginal proposition at best, and may disappear as the local peoples participate more fully in the Canadian economy. Meanwhile, however, the proposed flooding of their reservations presents a problem with high emotional overtones that could delay decision on a reservoir project indefinitely.

Another adverse result of the flooding of valley bottom land is the destruction of wildlife habitat - or more correctly, the substitution of a new aquatic habitat for the existing land-based habitat. In economic terms this substitution is seldom significant; the modification of wildlife habitat has been going on continually since the first day white man set foot on the North American Continent - and the consequences certainly have not prevented him from creating one of the highest standards of living on earth. However, here again the issue is frequently charged with emotion, and the arguments are not always rational.

There are then the aesthetic consequences of reservoir creation, the most adverse of such resulting from the flooding of uncleared forest. Clearing can be extremely expensive; hence few of our earlier reservoirs were cleared, and some of the results have been ugly indeed - as may be seen near the City of Vancouver and on Vancouver Island. It should be pointed out, however, that when the reservoirs in question were created to regulate water for power plants, the country had not reached its present state of affluence, and there is some doubt that the consumers of those days could, or would have paid the power rates necessary to provide for clearing of reservoirs. Times, however, have changed. We have become more affluent, and more aware of the need to preserve the amenities of our environment. Hence, we must practice at least selective clearing on any reservoirs created in the future, preferably including the removal of stumps. The question of spending large sums of money to clear inaccessible and isolated reservoir areas, however, is still a debatable one.

Another problem that may arise with the creation of a reservoir is the sloughing of banks and the starting of landslides around the periphery. Our glaciated terrain in Canada is particularly susceptible to such action because of the morainal, alluvial and lacustrine deposits that almost invariably line our valleys. For example, there are numerous such deposits along the Fraser Valley; and if the Moran Dam were ever built they would no doubt be subject to a good deal of sloughing. Moreover, there are three places around the proposed reservoir where large scale slides might occur. In one case the hillside is already in motion, and the British Columbia Railway tracks located thereon require periodic adjustment. If the bottom of the bank were submerged by a reservoir the sliding would probably accelerate. The thing to be remembered in most cases of bank erosion, however, is that conditions tend to stabilize eventually with the creation of a relatively flat beach below maximum reservoir level, and steeper slopes above; but before such stability is attained the limits of the reservoir may be extended considerably beyond the original water surface contour measured on the natural ground.

And finally, local transportation and communications may be adversely affected by a reservoir. Highways, railways, and their respective bridges may be submerged; but such flowage damages can almost invariably be rectified if sufficient money is spent in relocations. These expenditures, of course, form part of the capital cost of the reservoir. In some cases the resulting transportation network may even be improved.

Resume

In summary, it must be emphasized that the vital element in our lives is the fresh water which nature maintains in a constant cycle of movement - rising as evaporation from the oceans, drifting over adjacent land masses, condensing and falling on the land as precipitation, and finally flowing back to the sea through rivers and other water courses. Nature's cycle, however, is not uniform. It varies with the seasons from abundance to scarcity, and with the years from extreme highs to extreme lows. Two forms of natural water storage tend to dampen these fluctuations, one underground in porous soils, and the other in surface lakes - and to the latter man can add artificial storage reservoirs by building dams. These enable him to exert a measure of control over nature's streamflows - or domesticate them, as we might say - for his more abundant use.

The most fundamental use of streamflows thus controlled is, of course, the domestic consumptive use to sustain life. Next in importance is normally the use of controlled water for irrigation, (although such is not the case in our Canadian climate). Historically, the third most important use of storage reservoirs is for inland navigation. More recently their use has been greatly expanded to control water for the generation of power - a use on which much of Canada's prosperity is based. And then there are such uses as recreation, pollution abatement, and fish culture. All of these varied uses in the conservation and control of nature's streamflows are included in the modern concept of multipurpose projects.

On the other side of the ledger, there are some disadvantages to storage reservoirs since their creation involves the construction of barriers across rivers in the form of dams that interfere with the natural regime and flood land that might otherwise be used by man. In some cases these disadvantages are so severe as to preclude reservoir creation; particularly in thickly populated agricultural regions. In such a country as Canada, however, they can usually be so minimized by proper planning and allocation of development funds as to result in a clear and substantial profit.

In conclusion, I would like to adapt to Canada some of the words written by my friend, Guthrie Brown, and his co-author, T.A.L. Paton, with respect to the United Kingdom.

> "Everyone loves his own bit of country and laments the smallest change in it. The feeling is natural and as old as the human race: it demands respect. On the other hand, we cannot - - - - prevent the inhabitants of this land from increasing their numbers. Nor can we refuse them the higher standard of living which they demand. It is everyone's problem, and the engineers' problem in particular, to find means of further raising this standard - especially by 'directing the great forces of nature for the use and convenience of man' - - - - ." (3)

And this, in fact, is what we do when we create storage reservoirs to control the fluctuating and erratic streamflows of nature, and at the same time take care to minimize any adverse consequences.

REFERENCES

(1) "A history of dams", by Norman Smith. Published by Peter Davies, London, England

(2) "1970 Register of Dams in Canada", sponsored by Canadian National Committee of the International Commission on Large Dams

(3) "Power from Water", by T.A.L. Paton, C.M.G. and J. Guthrie Brown. Published by Leonard Hill (Books) Limited, Eden Street, London, N.W.1, England

APPENDIX B

1.1 THE NORTH SASKATCHEWAN RIVER

The source of the North Saskatchewan River is the Saskatchewan Glacier at the eastern end of the Columbia Icefield. Descending to the East through the Rocky Mountains and the foothills the River is joined by major tributaries such as the Alexandra, Mistaya, Cline, Bighorn, Ram and Clearwater rivers before reaching the community of Rocky Mountain House. Here, the River turns north and is joined by the Baptiste and Brazeau Rivers. Near Drayton Valley, the River turns to the northeast through Devon and Edmonton and thence easterly into Saskatchewan to its confluence with the South Saskatchewan River near Prince Albert. After initial examination of the River between the Bighorn Dam and the Saskatchewan border, the reach discussed in this report concentrates on the reach extending from 20 miles upstream of Rocky Mountain House to Edmonton as shown on Figure 1-1.

The flow regime on this reach is characterized by high summer discharge from snow melt and/or rain and low winter discharge when most of the precipitation occurs as snow. The maximum instantaneous discharge recorded at Edmonton was 205,000 cfs on June 28, 1915, and the minimum recorded mean monthly discharge was 591 cfs during January 1937. Recorded mean annual discharges are:

Rocky Mountain House	-	4,990 cfs (1913-76)
City of Edmonton	-	7,650 cfs (1912-76)
Brazeau River at Brazeau Dam	-	1,850 cfs (1962-76)

The area of the watershed within Alberta is 21,400 square miles or about 8% of the total area of the Province. Approximately 40% of Alberta's population lives in the basin with the major concentration being in the region around the capital city of Edmonton. The River provides the major source of water for human consumption within the Basin. It also provides the water necessary for agricultural, industrial, petrochemical, hydroelectric and thermal electric power generation requirements and is used for the corresponding disposal of treated waste water.

In addition to these primary uses, the River has an aesthetic appeal that enriches the territory through which it flows and gives rise to a variety of recreational activities. This is most evident on the flood plain of the River through the City of Edmonton, much of which has been converted into park lands by the Capital City Parks Commission. There is also the value of the extensive gravel deposits along the River for the recovery of aggregates. Several operators have mined these deposits from time to time after first obtaining a clay, marl, sand and gravel lease from the Provincial Government permitting removal of these materials from the river bed. There is no significant use of the River for navigation but there are several vehicular ferry crossings which may become unofficial ice crossings in winter. The number of these crossings continues to decline as more bridges are built.

The rapid industrial growth that took place in the Edmonton area during the 1950's was accompanied by a correspondingly rapid increase in withdrawals of fresh water from and discharges of polluted water to the North Saskatchewan River. As a result, the quality of the river water suffered serious deterioration from the discharge of both municipal and industrial wastes, the problem being most acute during the winter months because lowest flows occurred then and an ice cover impeded the purifying influences of air and sunlight. This situation led to a joint effort by the Province and Calgary Power Ltd. to improve water quality and at the same time produce power by developing combined water storage and hydroelectric power projects on the North Saskatchewan River at Brazeau and Bighorn.

1.2 STORAGE AND POWER PROJECTS

121 BRAZEAU

This development lies on the Brazeau River about 15 miles west of its confluence with the North Saskatchewan. Refer to Figure 1-1.

Construction commenced in 1960, and from the time the Brazeau Dam was high enough to store water safely it was used to augment winter flows.. In the first winter, that of 1961, 140,000 acre feet of storage was provided, and the amount was increased to 365,000 acre feet on completion of the main dam in 1962.

In following years Calgary Power constructed an outlet structure at the main dam, a power canal, intake, penstocks and powerhouse. The canal delivered water to the powerhouse which was located some 18 river miles downstream of the main dam. These facilities were commissioned in 1965 and the combined storage reservoir and power plant were subsequently operated to produce the twin benefits of higher winter flows in the North Saskatchewan and hydroelectric peaking power, the former to reduce pollution and the latter to complement the generation of the coal-fired thermal electric generating units of the system which operate most efficiently at uniform loads. In 1969 a permanent spillway was completed and the main dam was raised to increase usable reservoir storage to 425,000 acre feet.

122 BIGHORN

The Bighorn Dam location, eighty miles upstream of Rocky Mountain House had been known for many years as the largest water storage site on the North Saskatchewan River but technological difficulties had precluded its development in earlier years. However, the construction of a dam at this site eventually became possible following the successful development of technology for construction of deep concrete cut-off walls by means of slurry displacement. In recognition of the need for further augmentation of flows on the North Saskatchewan to supplement low winter flows downstream of Edmonton, the Province paid for the clearing of the reservoir, and contributed approximately 5 million dollars in return for downstream benefits.

The construction of the project began in 1969 and was completed in 1972. It included a 300-foot high earthfill dam creating the Abraham Lake reservoir with a utilizable capacity of 1,150,000 acre-feet and

supplying water to a powerhouse with an installed capacity of 120 megawatts in two units. This plant has since been given the primary responsibility for augmentation of winter flows in the River, each of its two units being capable of discharging slightly less than the regulated river flow. This has permitted greater flexibility in the operation of the Brazeau plant, whereby more of the water of the Brazeau reservoir can be used for peak load generation or kept in reserve for emergency usage, following a thermal plant outage.

123 WATER QUALITY AND QUANTITY

In the early 1950's water samples taken from the River during the winter low flow cycle showed relatively high concentrations of Biochemical Oxygen Demand (B.O.D.), Phenol content and chemical odour with low concentrations of dissolved oxygen. In June 1951, a report entitled "A Preliminary Survey of the Sanitary Condition of the North Saskatchewan River in the vicinity of Edmonton, Alberta" was issued by the Sanitary Engineering Division of the Department of Public Health. This document reported on the winter water quality problem and, subsequently, efforts were made both to improve the quality of waste water discharged to the River and to monitor water quality parameters each winter.

Significant improvements in water quality were recorded in the late 1950's; this was attributed to better municipal sewage treatment facilities in Edmonton and improved waste treatment and disposal practices by local industry. Winter flow augmentation using storage reservoirs commenced in 1961 and was increased by further water storage capacity in 1962, 1969 and 1972. Further improvements in water quality were observed during this period even though the riverside population was steadily increasing. This trend was probably due to increased dilution flows and further improvement in waste treatment practices. A history of mean and lowest dissolved oxygen measurements recorded at Fort Saskatchewan, 22 miles downstream of Edmonton, is shown on Figure 1-2.

The operation of the Brazeau and Bighorn storage reservoirs modified the annual distribution of flow downstream by storing some of the plentiful summer runoff and using it to augment the low flows during the ensuing winter. As a result, the average regulated flow at Edmonton for the months of November through March of the years 1973-76, with both reservoirs in operation, was 2.6 times the corresponding average natural flow for the same months of the 48 years of record preceding the inauguration of the Brazeau reservoir in 1961 (i.e. 1912-60); the average regulated flow for the lowest natural flow month of February in the 1973-76 period was 3.7 times the average natural flow in February in the 1912-60 period. A month-by-month comparison of the average winter flow at Edmonton before and after the inauguration of the Brazeau reservoir in 1961 and the Bighorn reservoir in 1972 is presented graphically in Figure 1-3.

montreal engineering company, limited

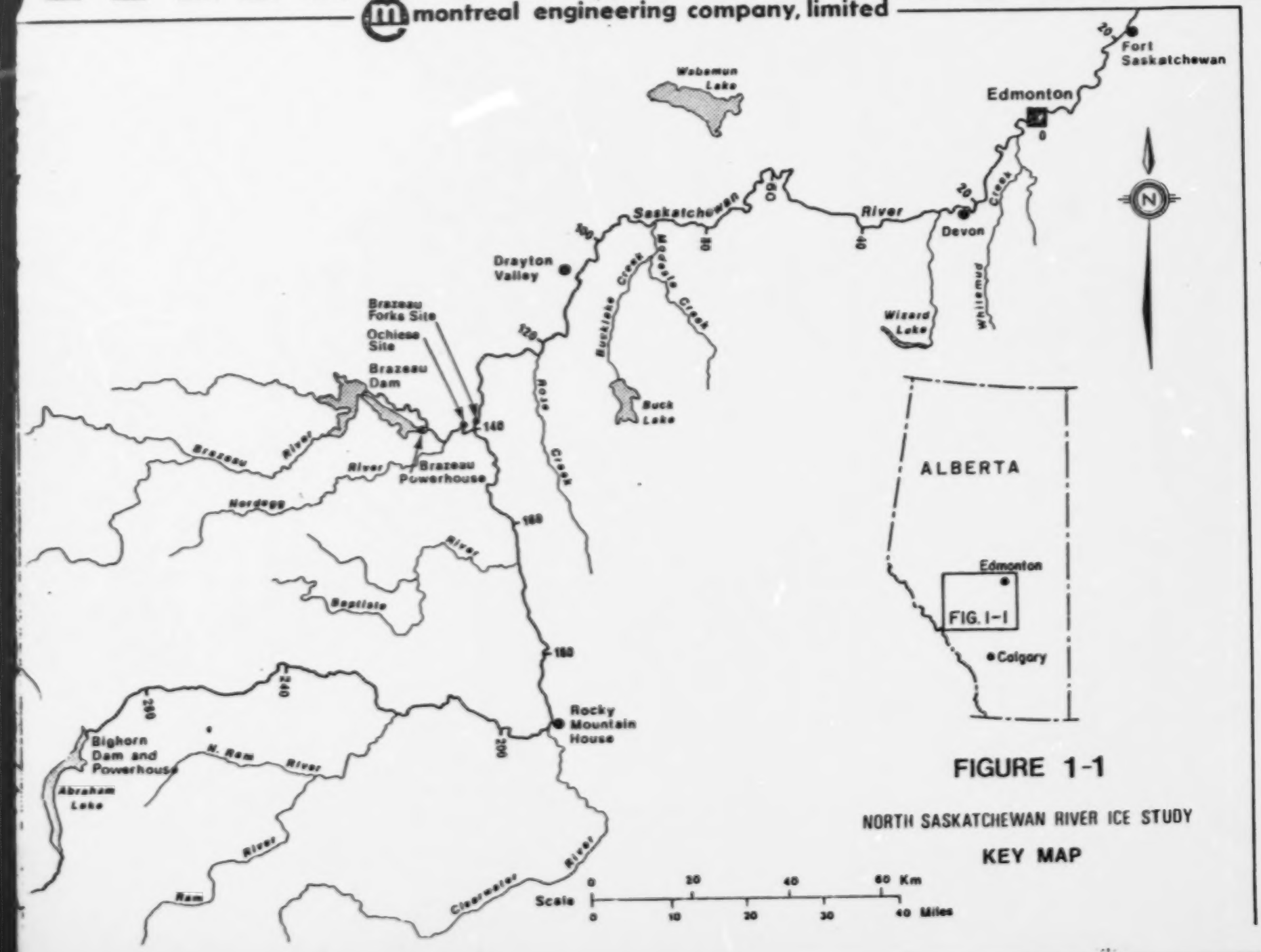
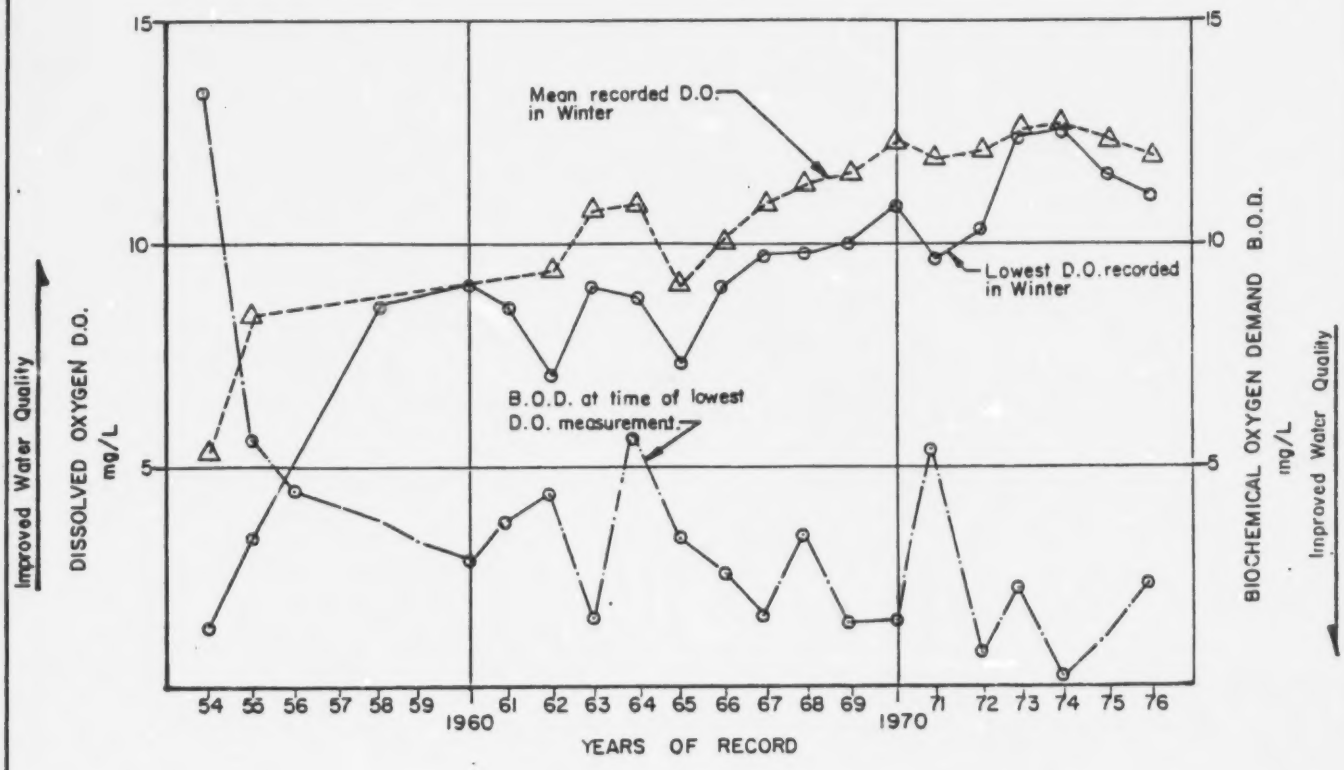


FIGURE 1-1

NORTH SASKATCHEWAN RIVER ICE STUDY

KEY MAP


Mean recorded D.O. in Winter
Lowest D.O. recorded in Winter
B.O.D. at time of lowest D.O. measurement
DISSOLVED OXYGEN D.O. mg/L
BIOCHEMICAL OXYGEN DEMAND B.O.D. mg/L
Improved Water Quality
Improved Water Quality
15
10
5
54 55 56 57 58 59 1960 61 62 63 64 65 66 67 68 69 1970 71 72 73 74 75 76
YEARS OF RECORD

NO. OF WINTER SAMPLES	56	101	0	0	1	0	4	2	25	24	31	22	31	20	23	12	12	9	5	4	4	5	8

NOTE:

(a) Data from intermittent samples taken by Alberta Environment at Water Quality Station 00AT05EA2150 "North Saskatchewan River at Fort Saskatchewan Bridge" 22 miles downstream of Edmonton.

(b) Winter data used. i.e. Months of November to March inclusive.

(c) Data Point above 1960 refers to 1959/1960 Winter and so on.

FIGURE 1-2

NORTH SASKATCHEWAN RIVER ICE STUDY

IMPROVEMENT OF WATER QUALITY DOWNSTREAM OF EDMONTON

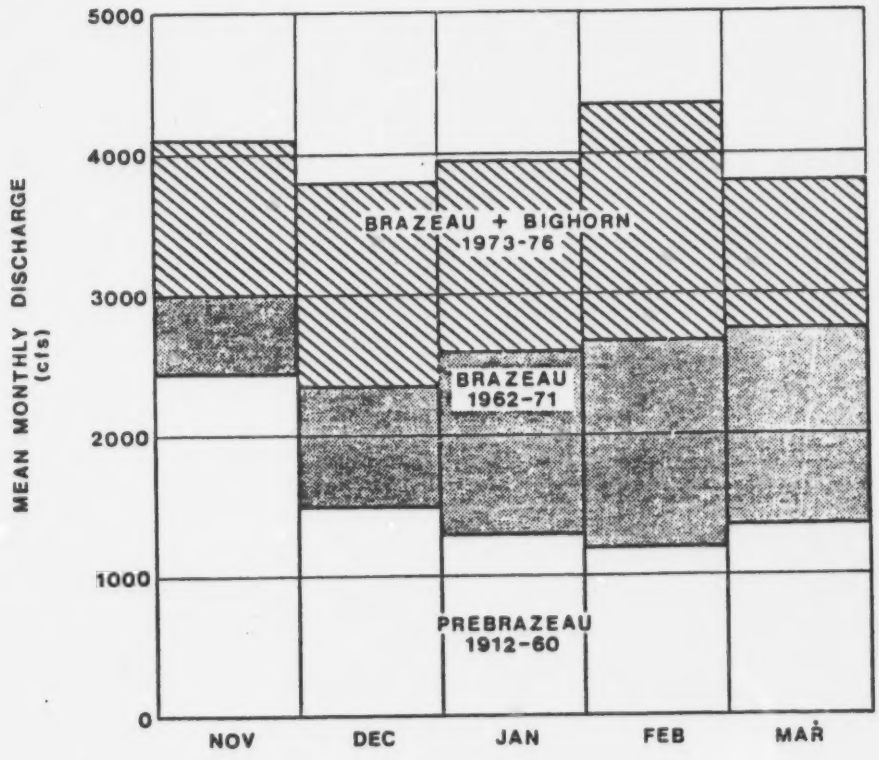


FIGURE I-3

NORTH SASKATCHEWAN RIVER ICE STUDY

MEAN MONTHLY DICHARGES AT EDMONTON

APPENDIX C

DAMS AND THE ENVIRONMENT

Note for the General Public

Preamble

This paper has been prepared by the Committee on the Environment of the International Commission on Large Dams (ICOLD).

The constitution of the Committee was as follows:-

E. T. HAMS	Great Britain	Chairman
R. FENZ	Austria	
J. A. BANDEIRA DE MELLO	Brazil	
M. KUUSKOSKI	Finland	
C. GEMAEHLING	France	
S. AKI	Japan	
H. ENGEL	Netherlands	
E. R. PARADINAS	Spain	
V. WANHAINEN	Sweden	
N. SCHNITTER	Switzerland	
R. D. HARZA	United States	
L. P. MIKHAILOV	U.S.S.R.	
M. MRVOS	Yugoslavia	
A. GONCALVES	Portugal	(Co-opted specialist)

DAMS AND THE ENVIRONMENT

INTRODUCTION

Water is vital to the very existence of man, animals and plants. The colonisation by man of various regions of the Earth has always taken account of the supply of water, along with food, warmth and shelter. Now the world population has reached levels where, in many places, water availability is critical to further development and even to the continued thriving or survival of existing communities.

In addition, the shortage of energy is having an increasing impact and renewable resources such as water power are much in demand.

Water resources can be developed for domestic and industrial consumption, for irrigation and for hydro-electricity, and such projects very often involve construction of dams. Dams may also be used for other water control projects with aims such as conservation, flood alleviation, coastal reclamation or protection, navigation and recreational facilities. The great majority of such dam projects are an obvious success.

Increasing sensitivity to environmental effects is an important development of the twentieth century. Dam engineers are very aware of the importance of environmental requirements and give full and early consideration to possible difficulties of this type. Dam construction causes environmental changes, but there are both beneficial and detrimental effects. In general, satisfactory and

economic solutions are developed to deal with any significant detrimental effects, but on occasion, a project may be abandoned if no such solutions can be found by the responsible engineers.

A significant problem arises from the difficulty of predicting the level of some environmental impacts, although their possible importance is apparent. On account of this, some mistakes have been made in the past. These have generally come about by one of two causes. Either there has been underestimation of detrimental impacts (usually by the Owner or his advisers) or else there has been overestimation (usually by public reaction, perhaps arising from a lack of full understanding). The latter may have led to abandonment of some projects of considerable overall benefit to the population, where a fuller study might have produced solutions which could have been shown to be satisfactory to all interested parties. The formation of the ICOLD Committee on the Environment was aimed at minimising the chance of errors from either cause.

This paper is intended to illustrate the concern and knowledge of dam engineers related to environmental matters. It describes procedures commonly adopted by dam engineers throughout the world to ensure the environmental safety of their projects. It enumerates the majority of known aspects of possible difficulty, with established solutions which have been successful in practice.

However, a short paper such as this cannot be comprehensive and those seeking information in depth have a wealth of literature to choose from, the details of which can be obtained from leading libraries or from ICOLD. A limited bibliography is also included at the end of this paper.

PLANNING THE PROJECT

The conception of a dam project usually originates with its intended owner or operator, though they may act through consultants or an externally funded study, which may be arranged internationally. The owner generally has economic criteria which must be met for the main aims of the project if it is to proceed. The feasibility study assesses the problems and gives an economic analysis for a range of feasible solutions. The study should take account of dealing with any potential environmental problems as, otherwise, the economic analysis is unrealistic. To assist the engineer at the feasibility stage and later, ICOLD has developed a matrix which acts as a checklist of all significant recognised environmental effects and allows interactions and possible solutions to be set out clearly, thus helping in their assessment.

In many countries, a dam project is subject to independent licensing procedures. These would normally be under the control of a Government department, separate from the owner and, in some countries, a Parliamentary Bill may have to be promoted. It is at this stage

that independent experts and the affected public may comment on environmental aspects, among others, through special meetings, panels of enquiry and the communications media. It is at this stage, too, that the Owner should be able to present his feasibility study or separate environmental impact study and in some countries, the latter is required by law. Such studies should satisfy all concerned that adequate measures will be taken to deal satisfactorily with any possible environmental difficulties.

Licences granted to the Owner after the enquiry or other licensing procedure will usually specify the environmental safeguards required and be backed by a power of enforcement.

During the construction, commissioning and operation of the project, the engineers and other specialists will be monitoring environmental factors and comparing performance with prediction. Flexibility is necessary to deal with any variation from prediction and, in this aspect, the ICOLD matrix is again of assistance in pointing out interactions. Reporting back to the independent licensing authority, or monitoring by it, will probably be recognised procedure.

For a dam project planned, commissioned and operated generally along these administrative lines, the prospects of an environmental success should be maximised.

ENVIRONMENTAL PROBLEMS AND REMEDIES

Passage Past the Dam

A dam is an obstacle to the passage of flotsam, logs, ice, fish and shipping. This can be overcome by the provision of chutes and/or rakes for floating debris; fish ladders or lifts; and locks. (1)

Sediments

Sediment and bed load is normally deposited in a reservoir instead of continuing downstream. Water discharged at the dam with no such load is "hungry" and river training works may be built downstream to prevent or control erosion of banks and river bed. Silt previously deposited on arable land may have to be replaced by fertiliser and this could have some advantages if applied with care. Under certain hydrological conditions, many of these effects can be partially overcome by passing silt-laden water through a low level spillway or sluice at the start of a flood and closing the gates to impound the cleaner flows later in the flood. This latter procedure could also be advantageous related to suspended nutrients which may be of importance to downstream fish life. The problem of sediment (2)
accumulation in a reservoir is often alleviated by erosion control measures in the upstream catchment, such as reafforestation and soil conservation. (3)

Measurement, prediction and control of sedimentation in reservoirs is under study by a multi-national technical committee of ICOLD. The committee's report will provide guidance for dam engineers in solving sedimentation problems.

Water Releases

Generally, a large reservoir serves as a settling basin and the cloudiness or turbidity of water released to the river downstream is reduced. However, there are cases where a large quantity of fine particles of low settling velocity is suspended in the inflowing water at times of high run off. Retention in the reservoir then results in

longer term persistence of turbidity in water released to the river downstream. Such a condition can create problems with recreation, fisheries and water use as well as marring river side amenities.

As the turbid water is often retained within a reservoir as a discreet horizontal layer, an intake with selective outlet levels is effective for the discharge of cleaner water. (4)

Minor floods along a waterway can be important, especially to downstream fish life, and these can be continued by special releases of compensation water through the dam. Larger releases may be required for periodic scouring of river or estuary banks or bars where such features develop because of the dam's regulating effect on large natural floods.

Dried river beds below dams are unsightly and detrimental to fishing. In many cases, agreed compensation water releases through the dam avoid this problem.

Animals

(5) Land animals trapped by rising reservoir waters can be rescued by "Noah's Ark" type operation. Water fowl and fish, on the other hand, benefit from new reservoirs and flourish, as may migrating geese and similar species taking advantage of a new stopover area. (5) On the other hand, migrating routes of land animals may be impeded and alternatives may need to be provided with suitable encouragement for the animals.

Climate

New microclimates are created by large, new reservoirs and these have a variety of effects, including possible fog formation and, also, somewhat modified or increased rainfall patterns. Predictions of these effects are possible based largely on air and water temperature.

Water Temperature

Temperature differentials occur in deep reservoirs with the upper levels being more variable and warmer in warm seasons. Offtakes at several levels permit selection of warmer or colder water. Similarly, dissolved oxygen content varies with depth and can become deficient at deeper levels. Again, offtakes at various levels permit selection and, in any case, released water recovers its normal oxygen content by contact with the atmosphere very quickly.

Temperature problems related to releases from cooling water systems for power stations and other industrial installations can often be alleviated by judicious use of reservoirs.

Gases

In rare instances, supersaturation of reservoir releases with nitrogen and oxygen is possible below high spillways with submerged buckets, particularly close to the water surface. This condition can be detrimental to fish life, but properly designed deflectors will alleviate the condition.

Salts

Dissolved salts entering a reservoir by intermittent "slugs" in an upstream river are diluted by the reservoir and the releases will normally be less concentrated. However, evaporation from such a reservoir in hot climates can cause gradual salt concentration. These effects can be modelled mathematically for prediction purposes.

Eutrophication

Eutrophication can develop, particularly in new reservoirs. An excess of nutrients produces a bloom of plankton, algae and weed growth. These growths die and, when rotting on the bottom, use up all available oxygen at depth. Sulphuretted hydrogen is formed and the water is unfit for domestic use. In the river stretch immediately downstream, fish biota may be threatened. The first remedy is the thorough clearance of new reservoir areas prior to impounding. Trees removed from the reservoir bed can often be used for timber or fuel. Other useful lines of action include water aeration, purifying inflow and building interception ditches to carry away from the reservoir any land run-off liable to contain traces of fertiliser, particularly compounds of nitrogen and phosphorus.

A separate approach is the introduction of plant eating fish such as the Chinese carp, but considerable care is always necessary that exotic species do not upset the balance of natural fauna.

Flora

Aquatic plant life can thrive in a reservoir to a level which hampers water abstraction, power production, navigation and fishing.

Some controls are available such as the dropping of reservoir levels and the spray application of selective herbicides on the dried roots; mechanical removal of infestations at the very beginning of their development; and the use of plant parasites for biological control.

Fauna

Aquatic fauna thrive in many new reservoirs and this is generally advantageous. However, the effect of introducing any new species requires careful consideration.

Groundwater

Groundwater levels may be raised or lowered in different areas affected by dam schemes and this may be particularly significant with dams and storages on lowland rivers. Water supply and agriculture can be affected by such changes. If required, a raising can be controlled by drainage measures and a lowering can be remedied by control weirs, cutoffs or artificial recharge.

Landslides

In steep valleys which are to be flooded, care is required to assess the potential for landslips into the new reservoir, generally caused by changed groundwater conditions or rapid reservoir drawdown. A soil mechanics and geological investigation can detect such areas. Drainage and stabilising works are generally possible and instrumentation can be established to detect incipient movements and water pressure changes.

Earthquakes

For high dams impounding large volumes of water, and in some other particular cases, special investigations should be carried out concerning possible risks of induced earthquakes. The state of rock stress should be assessed and evidence of any geologically recent volcanic formations should be looked for along with any recently active faults, particularly of large displacements or lengths. A technical committee of ICOLD has been set up to study this subject specifically.

Population Movements

Population movements from reservoir areas may be brought about by dam projects. Although displacement as such is disruptive, the opportunity is normally taken of providing improved housing, social amenities and, often, work prospects in the new settlements. Sociological surveys and studies should be undertaken and the affected population should be kept well informed with an appropriate communications and consultative programme.

Agriculture

Agriculturally productive valley bottoms are sometimes inundated by dam projects. On the other hand, larger areas downstream are equally often brought into agricultural production because of assured water supplies for irrigation or because of new protection, provided by the dam, from previously damaging flooding. (7)

Archaeology

Archaeological sites are sometimes threatened by new reservoirs. In very important cases, such as Abu Simbel in Egypt, internationally financed projects for protection or moving have been arranged. In other cases, the programme allows for prior documentation and recording of the sites and the removal of valuable artefacts.

HEALTH PROBLEMS IN TROPICAL & SUB-TROPICAL AREAS

Tropical and sub-tropical diseases such as malaria, bilharzia and onchocerciasis (filaria), are often endemic in hot, damp regions where new reservoirs are planned and built. These diseases involve "host" or "vector" organisms in which a parasite lives for part of its life, subsequently being transmitted to man. These hosts and vectors require fresh water at certain stages of their life cycle and a new reservoir may increase the size of the hosts' habitat, promoting their expansion.

The mosquito vector for malaria uses auxiliary water systems and marginal areas for breeding, not the main reservoir, and the black fly vector for onchocerciasis develops in fast flowing water such as found near spillways or tailrace outlets. The bilharzia vector is an aquatic snail, thriving on aquatic plants in still or slow-flowing water. Man is contaminated by fluke larvae leaving the snails and entering parts of the human body exposed in the water. Marginal lake areas are, therefore, critical.

New reservoirs can also, in certain circumstances, encourage amoebiasis, and other infections, which do not involve an intermediate host.

Prevention or substantial alleviation of colonisation of new reservoirs by host flies, mosquitoes and molluscs can be achieved by:-

a) Educating local population in health, hygiene, community awareness and medical prophylaxis;

b) Clearance of vegetation before lake filling;

c) Filling, deepening, or draining of marginal areas which might become swampy during reservoir drawdown;

d) Raising and lowering reservoir level weekly during egg-laying season;

e) Using pesticides. These must be sprayed and spread frequently and they must not be toxic to man or edible fish;

f) Growing of vegetation known to be toxic to bilharzia snails.

BENEFICIAL SIDE EFFECTS

A dam project may be truly multi-purpose (e.g. hydro-electricity, flood control and irrigation), or it may be mainly for a single purpose, such as potable water supply. In most instances, there will be at least one secondary water control or water resource advantage (e.g. a water supply project may have a subsidiary flood control effect). These water control or water resource secondary effects are considered part of the main project's economics and are excluded from these remarks. However, other spin-off effects of dam projects can be significantly advantageous.

Although dam projects sometimes submerge waterfalls, cascades and gorges, it is often the case that reservoirs add interest and beauty to a landscape. The dam itself can be a great tourist attraction and appurtenant works such as fish ladders, locks, power stations and channels add further interest. Tourism and leisure pursuits can be encouraged by establishing parks, camps, water sport and swimming areas, subject to health requirements. There need be no restriction to public access if proper safety measures, sanitary facilities and supervisory control are provided. (8a & 8b)

Road realignments, because of a new reservoir and access roads to the project area, give opportunity of upgrading communications and opening up new areas for economic or tourist development, and new water navigation is also sometimes effective in this respect.

Fresh water fishery opportunities are substantial in new reservoirs, both for sporting and commercial exploitation. The latter can take the form of fish farming.

New reservoirs can provide very significant fire break advantages in areas where bush and forest fires are a risk.

LATER MONITORING AND CONTROL

During study, design, construction and commissioning, engineers representing the Owner and the Licensing Authority are actively engaged on the dam project. Environmental requirements are monitored effectively and there can be prompt response to any variations from predicted performance.

For later stages of the life of the project, monitoring should be maintained, although clearly a less continuous system is satisfactory.

The Owner normally has some permanent professional or technical staff stationed at or responsible for the dam project and included in their duties should be monitoring of specific environmental effects. In addition, such staff should be briefed to observe keenly and report any other items or events which could be of significance. Excursions from predicted behaviour and unusual events should be brought to the immediate attention of the authorities so that an expert can investigate.

In addition to these continuing monitoring activities by the Owner, there may be independent inspections at specified time intervals. These may be made by an individual or by a team of experts in various disciplines and could be specified in the licensing approval.

Such procedures act as a considerable long-term safeguard and are generally economic. Problems can often be dealt with at the incipient stage rather than when they become intractable.

THE ENVIRONMENT AND MANAGEMENT OF WATER RESOURCES

Water is a very significant element of the environment. It is also essential to man and to man's niche in world ecology.

Man's needs for water increases and dams and reservoirs are an outcome which is inevitable.

By a combination of scientific study, engineering and management, dam projects can be achieved in a manner dedicated equally to maximisation of success of main project aims and of environmental protection and improvement. Environmental changes will occur, but change does not mean destruction. The impact of the changes can be controlled successfully and, on balance, rendered beneficial.

BIBLIOGRAPHY

Ackermann, W.C. et al	Man-made Lakes: Their Problems and Environmental Effects, American Geophysical Union, Washington D.C. 1973
American Society of Civil Engineers	Environmental Effects of Large Dams, New York 1973
ICOLD	Question 40, Proc. 11th Congress, Madrid 1973
ICOLD	Question 47, Proc. 12th Congress, Mexico 1976
ICOLD	Committee on Damming & the Environment, Report & Synthesis, Paris 1980
Int. Bank for Reconstruction and Development	Environmental Health and Human Ecologic Considerations in Economic Development Projects, Washington D.C. 1974
Lagler, Karl F.	Man-made Lakes: Planning and Development UNDP/FAO, Rome 1969
SCOPE Report 2.	Man-made Lakes as Modified Ecosystems, International Council of Scientific Unions, Scientific Committee on Problems of the Environment, Paris 1972

APPENDIX D

B.C. Hydro
Box 12121 · 555 West Hastings Street
Vancouver B.C. V6B 4T6
Cable Address "Interpow"
Telex 04-54456

For Personal Contact
Dial 663-2743

25 August 1983

File: 929-

Mr. D. Duguid
3841 Willshire Road
RR #1
Chemainus, B.C.
V0R 1K0

Dear Dave:

Yukon River Basin Study

Reference is made to your recent request for information on the use of B.C. Hydro reservoirs by other utilities for storing their energy. I understand that this information is needed to complete your assignment "Storage and the Yukon Hydroelectric Potential - A Long Range Planning Issue" for the Yukon River Basin Study.

B.C. Hydro has from time to time stored energy in its reservoirs for other utilities. The terms and conditions under which this has taken place have usually included the following:

1. The amount of energy to be stored, the timing of storage and the rate of delivery of energy to the storage will be subject to mutual agreement between B.C. Hydro and the other utility.

2. The stored energy will be located in the top portion of the reservoir. If any spill occurs, an equivalent amount of energy will be deducted from the stored energy.

3. If energy is stored by more than one other utility, any energy spilled will be deducted from the stored energy on "last stored, first spilled" basis.

4. B.C. Hydro will make reasonable efforts to avoid spill of energy. If spill appears likely, B.C. Hydro will give as much notice as practicable.

5. Stored energy will be returned by B.C. Hydro to the other utility at their request, at times and rates of delivery as mutually agreed.

...2

6. B.C. Hydro's obligation to return stored energy will be limited to those times when such energy can be generated from hydroelectric plants. Any sale of energy undertaken by B.C. Hydro will take precedence over return of the stored energy.

7. When stored energy is returned to the other utility there will be a service charge payable to B.C. Hydro. The amount of service charge will be determined at the time of storage.

A number of utilities have found it beneficial to store their energy in B.C. Hydro reservoirs, mainly for the purpose of reducing spill at their own reservoirs. If a transmission line is built to interconnect the B.C. Hydro and Yukon systems, there will be similar opportunities for Yukon to store its surplus energy in B.C. Hydro reservoirs, in accordance with the terms and conditions described above.

In regard to your request for public information on reservoir operation, I am enclosing a copy of "Characteristics of Hydroelectric Generating Systems". This is an extract from a larger report "Electric System Plans 1981 - 1995" which is now out of print. However, you are welcome to come and read the full report in our office at your convenience.

I hope this memo will be of assistance in the preparation of your assignment for the Yukon River Basin Study.

Yours very truly,

P.A. Kadak
Supervisor Hydro Resources
Generation Planning Department

Encl.

cc: Mr. B. Brickman
Chairman, Energy Work Group
Yukon River Basin Study

electric system will be 45 700 GW.h (millions of kW.h) as shown in Table 2-1.

(c) Characteristics of Hydroelectric Generating Systems

Because most of the electricity provided by the B.C. Hydro system comes from hydroelectric sources, the amount of electric energy available fluctuates with variations in river flows. Therefore, the electric system must be planned and operated in such a way as to protect customers from shortages of electricity in periods of low streamflows while making the best possible use of surplus water available when streamflows are average or higher.

To understand the hydroelectric power system, it is necessary to understand the difference between its peak capacity (the most electricity its power plants can generate over a 1 hour peak period, which normally occurs during December or January), and its energy capability (the average amount of electricity it can produce under varying streamflow conditions, over a given period, usually a year).

A hydroelectric plant without water is no more use than a thermal plant without fuel. With the latter, it is usually possible to acquire additional amounts of fuel as needed to keep the plant producing at capacity. But with a hydroelectric plant, once the reservoir is drawn down, the plant cannot produce any more electricity until additional water enters the reservoir (primarily during annual spring run-offs).

In addition to supplying the annual energy demand, the B.C. Hydro power system must be able to meet the peak power loads each winter, and it must also have a minimum margin of reserve generating capacity (usually 12 to 15 percent of peak load) over

2.1 THE ELECTRIC SYSTEM - (Cont'd)

and above the forecast peak to allow for scheduled and unscheduled outages of equipment. The exact amount of capacity reserve required is based on a statistical analysis of the probability of outages on each unit in the system.

The rivers of British Columbia have flows that are highly variable throughout the year with low flows generally occurring during the cold winter period followed by high runoff in the spring and early summer periods when the snowpack melts. Reservoir storage is used to regulate these flows and attempt to "shape" them to the pattern of load demand. Because this storage is limited, it is sometimes necessary to pass flows in excess of the powerplant capacity and the excess flow has to be spilled. The more the capacity of the powerplant, the smaller the amount of water spilled will be.

The optimum capacity of each plant is determined by balancing the cost of added powerplant equipment against gains in energy due to the reduced spill. This results in more capacity in the system as a whole than necessary to meet the peak load requirement in the December-January period. Hence meeting the peak load demand is not the determining factor for providing additions to the generation system.

The installed generating capacity at new hydroelectric projects is determined on the basis of their ability to generate an optimum amount of energy, rather than on the need for additional peaking capacity. If thermal-electric power is added to the system in future, the peak reserve requirement may become more important.

2.2 THE PLANNING PROCESS

It takes many years to plan a new electric power development and bring it into production. For this reason, B.C. Hydro must always

APPENDIX E

BIBLIOGRAPHY AND REFERENCES

1. University of British Columbia (1972), Energy and Environment, Institute of Resource Ecology, H.R. McMillan Lectures for 1971 p. 162-175, The Environmental Impact of Hydro Power, Peter A. Larkin

2. U.S. Committee on Large Dams USCOLD Newsletter No. 71 July 1973 Azure Pumped Storage Project p. 7-9, Columbia River 1983 System Regulation p. 12

3. Alberta Fishing Guide, Vol., 7 1978, Fishing in Alberta p. 1

4. W.P. Creager and J.D. Justin, John Wiley and Son, Hydroelectric Handbook second edition 1950

5. Edward Kuiper, Water Resources Project Economics Butterworths, London, 1971

6. Crippen Engineering Ltd., 22 Nov. 1973, The Value of a Dependable Water Supply to the Aishihik Project, and the Future Yukon Territory Power System

7. Monenco Consultants Pacific Ltd., Ice Conditions on the Yukon River at Whitehorse, June 1979

8. Monenco Consultants Pacific Ltd., Mid-Yukon Project Preliminary Mitigation and Enhancement Study, July 1980

9. Monenco Consultants Pacific Ltd., Hydroelectric Development on the Yukon River and the Gold Rush Park Concept, July 1980

10. Water Survey of Canada Environment Canada, Historical Streamflow Summary Yukon and Northwest Territories to 1979, 1980

11. Monenco Consultants Pacific Ltd., Inventory of Yukon Hydroelectric Sites, 20 Oct. 1982

12. Water Resources Branch, Department of Northern Affairs and National Resources. Yukon River Basin Report. (4 Volumes). December 1962.

13. Water Resources Branch, Department of Mines and Technical Surveys. A Preliminary Appraisal of the Yukon-Taiya and Yukon-Taku Storage and Power Schemes. (3 Volumes). August 1966.

14. Monenco Consultants Pacific Ltd., Mid-Yukon Feasibility Study, Nov. 1981, Year 1

15. B.C. Hydro, Electric Transmission Interconnection Study, System Engineering Division. Project Report. Energy No. 2, May 1983.

16. Montreal Engineering Company, Limited, North Saskatchewan River Ice Study, December 1978.

17. Sexton, J.K., Water Storage Reservoirs, CANCOLD Bulletin, March 1975.